BALANCE PERFORMANCE OF UNDERGRADUATE DANCERS: AN EVALUATION OF CURRENT AND NOVEL APPROACHES IN BALANCE TESTING AND TRAINING IN THEATRICAL DANCE

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Abstract

Balance skills are considered essential for dancers as they are required to perform complex, virtuoso movements. However, there is a dearth of evidence on the appropriateness of existing balance tests and training protocols for dancers. The aims of this thesis were to: (a) test sequentially the assumptions of associations between different field balance tests and between dancers' balance ability and their dance performance, followed by an examination of the relevance of sports functional balance tests on dancers and, building on the first aim, (b) develop a reliable, dance-specific balance scoring tool and testing protocol examining the effects of balance training in a randomised controlled trial.

Study 1 assessed associations between five field balance tests: Star Excursion Balance Test (SEBT), the modified Romberg test, the Airplane test, the BioSway Balance System (Biodex, USA) and a dance-specific pirouette test. Results showed strongest relationships between some (SEBT) reach directions ($p<0.01$), but very weak to moderate relationships between some balance tests including some SEBT directions, Romberg, Airplane, Biosway, and pirouette ($p<0.01$ and $p<0.05$).

Study 2 assessed associations between balance ability and dance performance comparing the five field tests from Study 1 to the same participants' technique and repertoire performance scores in ballet, contemporary, and jazz genres. Results showed a low predictive association of balance ability on dance performance ($p<0.01$ and $p<0.05$). The first two studies demonstrated low predictive association between field tests and between balance ability and dance performance, suggesting limitations in the sensitivity of the tests for the dance population.

Thus, studies 3 and 4 used a more functional tool to assess its sensitivity towards balance ability of the undergraduate population. Study 3 examined the effects of potential bilateral differences on dynamic postural stability during single-leg landing using a time to

stabilisation protocol. Asymmetric training has been suggested in the literature but results showed that bilateral differences did not correlate with dancers' balance ability; no significant differences were found in dynamic postural stability between the right and left leg and poor effect size was noted. Next, Study 4 examined the effects of fatigue using the same time to stabilisation protocol as Study 3. Fatigue has been associated with injury levels in dancers and balance ability in pre-professional dancers. Results showed that a fatigue condition (Dance Aerobic Fitness Test) had no significant effect on dancers' postural stability or bilateral differences. Similar to the earlier studies, the functional test protocols in these two studies were limited to basic movements for dancers and lacked the sensitivity to measure variable postural control adaptations.

Building on the findings of the first four studies, Study 5 developed a novel Accumulation Balance Score designed to gather data on postural stability and control in a variety of dance-specific settings. Results showed excellent interrater (ICC=0.963) and intrarater (0.992) reliability. Study 6 examined the effects of balance training on postural stability in a randomised trial. To capture postural control data, the Accumulation Balance Score was applied to the data. Results showed effects of training on some balance tasks: time ($p=0.048$), distance ($p=0.004$), and in various balances: arms ($p=.014$), legs ($p=.016$ and $p=.001$ and $p=.042$), and spine ($p=.041$ and $p=.018$). Post hoc tests revealed mixed findings between groups. Collectively, the results in this thesis revealed that current balance testing and training may not be functionally relevant for dancers with expertise in organising and patterning balance strategies. In contrast, aspects of novel dance-specific balance training may challenge dancers' entrained responses, and the reliable Accumulation Balance Score can be applied to more novel approaches and protocols in assessing balance, more closely replicating embodied dance experience with ecological validity. For the first time, postural stability and postural control can be measured together in a balance assessment.

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1 Introduction

1.1 Definitions of key areas

Balance is a key skill for dancers in terms of both postural stability and postural control. However, in dance training and performance, the word balance is commonly used with little reference to the specific associations to stability and control. It might be argued that the lack of concise definitions of balance could limit accuracy in implementing balance training strategies and appropriate criteria for balance assessments in performance. Whilst dancers may have intuitive responses to working on balance skills, further clarity of the definitions of the term balance would allow dancers, and those who train them, to work on precise interpretations of any balance deficits and subsequent adaptations. The definition of balance is still much debated by academics and clinicians (Pollock *et al.,* 2000; Horak, Wrisley and Frank, 2009), and current assessments of human balance, for both general populations and dancers and athletes, examine postural stability and control for a variety of reasons. To date, there is no evidence of a systematic approach for testing the above populations. However, it is important to clarify and distinguish key terms at this stage of the thesis. Therefore, and with regard to the challenges just noted, definitions of the key areas are outlined below.

1.1.1 Balance

Human balance has been defined as an individual's ability to control equilibrium (Grimshaw *et al.,* 2006; Hall, 2007), and a multidimensional concept with the ability to resist falling (Pollock *et al.,* 2000). These definitions are outlined in studies on balance from the mechanical and clinical perspectives, and Pollock and colleagues (2000) argue for the need for a systematic approach to defining balance to improve scientific evaluation of clinical assessments. Balance in dance is described as a complex phenomenon (Simmons, 2005a;

Batson, 2010) but there are no studies defining the interpretation of balance in this field. The term “balance” is commonly associated with the terms stability and postural control (Pollock *et al.*, 2000). The balance process maintains the position of the body’s centre of gravity over the base of support, relying on continuous, rapid feedback from visual, vestibular, and somatosensory structures and followed by coordinated neuromuscular actions (Nashner, 1997; Pollock *et al.*, 2000). Each of the sensory systems provides specific information that enables the brain and nervous system to make the required muscle responses to achieve a state of balance (Krasnow and Wilmerding, 2015).

Balance is required during both locomotion and stance, thus, two major types of balance have been identified. Static balance is the ability to maintain postural stability with the centre of mass over the base of support with minimal movement or at rest (Hrysomallis, 2011), whereas dynamic balance is the ability to maintain postural stability with the centre of mass over the base of support with the body in motion (Hrysomallis, 2011). Balance control is a highly complex function and involves many different underlying systems. These interacting systems have been identified as: biomechanical constraints, stability limits/verticality, anticipatory postural adjustments, postural responses, sensory orientation, and stability in gait in the Balance Evaluation Systems Test (BESTest) (Horak *et al.*, 2009).

1.1.2 Postural stability

Mechanically, a form of stability exists if the line of gravity falls within the base of support. It increases with a larger base of support, a lower centre of gravity, or a more central centre of gravity within the base of support (Bell, 1998). Pollock and colleagues (2000) state that stability is the inherent ability of a person to maintain, achieve, or restore a state of balance (and thereby not fall). Interestingly, they argue that postural stability is similar to postural control, but it is an “inherent ability” and not an “act”, and that this inherent ability relates to an individual's motor and sensory systems (Nashner, 1982; Horak, 1987) and the person's physical properties (Pollock *et al.,* 2000).

1.1.3 Postural control

When the line of gravity falls outside of the base of support, humans have an inherent ability to use muscular activity to counteract the force of gravity and prevent falling. This is termed "balance control" or more commonly, "postural control" (Pollock *et al.,* 2000). Postural control can be defined as the act of maintaining, achieving, or restoring a state of balance during any activity or posture (Pollock *et al.,* 2000). Postural control strategies can be either predictive (anticipatory) or reactive (compensatory), or a combination of both strategies (Pollock *et al.,* 2000; Horack, Wrisley and Frank, 2009). Responses may be "fixed-support", for example, an ankle strategy (the line of gravity moves but the base of support remains unaltered), or "change-in-support", for example, stepping (the base of support is moved so the line of gravity intersects it) (Pollock *et al.,* 2000).

In this thesis, the aforementioned definitions of postural stability and postural control are applied to the relevant studies.

1.2 Background

Dancers exhibit virtuoso feats of balance which excites and inspires audiences. Accomplishing balance can help express a certain meaning or emotion in performance or simply, be a virtuoso action in itself. This versatility in balance ability is well recognised and dancers have been described as balance "experts" (Stins *et al.,* 2009), and yet, studies on dancers have shown mixed findings in this area (Perrin *et al.,* 2002; Simmons, 2005a; Kuczyński, Szymańska and Bieć, 2011; Ambegaonkar *et al.,* 2013). This elicits the question of suitability and relevance of testing procedures for balance ability on dancers. If these artists can meet the balance challenges in adage and multiple turns for example, why might they only demonstrate the same level of ability as non dancers in some balance tasks (Perrin *et al.,* 2002; Pérez *et al.*, 2014)? Do complex balance strategies play a part? Dancers have exhibited complex coordination skills in postural control (Golomer *et al.,* 2009a; Jarvis, Smith and Kulig, 2014). However, complex strategies employed by dancers may diminish performance and increase risk of injury. Gaining a better understanding of the assessment of dancers' balance may help to gauge the functional relevance of current tests and protocols.

Balance skills have featured in dance since ancient times; in early Greek, Chinese, Indian, and Egyptian art, dancers are depicted in individual or group stance poses (Gombrich, 1972; Lonsdale, 1981). Centuries later, in Europe, stylised movement became more daring and technical through the periods of court ballet and ballet d'action, the era of the first professional performers in theatrical dance (Au, 1988). Sustained skilful balances came into prominence in the Romantic ballets in the first half of the nineteenth century. Balance skills became an essential part of the ballet repertoire and artistic movement, helping the ballerina give the illusion of an ethereal sylph whilst balancing on the tips of their toes (Guest, 1980). Later, the Classical period of ballet saw the rise of the virtuoso ballerina, and variations were choreographed to display ever more technically demanding feats of balance, such as the spectacular sequence of sustained adage balances in Odette's solo variations of Act II in *Swan Lake* by Petipa and Ivanov (1895). In the 20th century, across the theatrical genres of ballet, contemporary, and jazz, balance skills were more challenged as repertoire became more off centre, experimental, and "hybrid" (Au, 1988; Batson, 2010).

Today, dancers can be required to perform in different genres even in one company season; this suggests that dancers need to be versatile in their responses to balance tasks in diverse repertoire (Schmit *et al.*, 2005; Bläsing *et al.,* 2012). Exhibiting variability in postural control and stabilising strategies reveals expertise in one way but it may not tell the whole story. Codified dance training aims to achieve balance mastery but may diminish the variety of sensory responses available to dancers. For example, certain genres rely more heavily on visual dominant strategies such as mirrors, but entrainment also may reduce the ability for somatosensory shifts. Furthermore, current balance testing tools may not be sensitive enough to measure the postural adjustments and variability exhibited by dancers (Golomer *et al.*, 2009a).

Previous research in dance appears to focus on the premise that current balance assessment protocols are appropriate for a dance population. The mixed findings present inconclusive evidence of the functional relevance of the present tests and study designs, in relation to dancers' acknowledged expertise and variability in employing balance strategies. To date, no novel dance-specific balance tests or training protocols have been designed that more closely replicate the complexities of dance performance and dancers' reactive and predictive reponses in balance tasks. Furthermore, current assessment tools are limited to single actions; to our knowledge, there are no assessment tools that can be applied to both single balance tasks and movement sequences.

2 Thesis structure, aims and hypotheses

The key aim of the thesis was to create a dance-specific balance test and testing protocol building on tests which are either sports based or use ballet-codified movement patterns. A sequential order of studies was designed culminating in the design of a new balance tool and protocol. The theatrical dance genres of ballet, contemporary and jazz were selected as a context for the studies as they represent the field of professional dance (but not competition dance) and the training of the undergraduate participants. However, further genres were included in the systematic review if performed in the professional theatrical domain. This research was influenced by practitioner wisdom and practically driven by the needs of dancers and practitioners as observed and experienced by the researcher over a number of decades of professional work in the field. The field of dance science is relatively new, thus, at times, a more experimental approach has been conducted, including novel adaptations to training and test protocols.

This thesis is organised in inter-related chapters. The chapters develop through a carefully designed plan of studies to assess current balance testing tools and protocols utilised in the dance field, and to evaluate their relevance for dancers. The last two studies examine firstly, the development of a novel balance score system which is then applied in a novel dance-specific dance test. Preceded by a systematic review of the literature, the core of the thesis comprises six experimental studies, as follows:

Study 1 (Chapter 4) tests the hypothesis that associations would not be found between field balance measures used in assessing dancers' balance. The five tests measure postural stability and were revealed in the systematic literature review (Chapter 3). Most of these tests were designed originally for sports and general populations, but the pirouette tests are dance-specific and evident in recent studies. The five tests comprise of three dynamic balance tests: Star Excursion Balance Test (Gribble *et al.*, 2012), a pirouette test (Denardi et al., 2008;

Golomer *et al.*, 2009b; Lin *et al.*, 2011), the Airplane test (Richardson *et al.*, 2010), and two static balance tests: modified Romberg (Rogers, 1980; Richardson *et al.*, 2010), the Biosway™ (Rein *et al.*, 2011).

Study 2 (Chapter 5) examines assocations between the tests from Study 1 and in-house performance scores in ballet, contemporary, and jazz genres (theatrical dance) to test the widely held assumption that balance ability is associated with dance performance (competency). However, in the current literature, there is no clear evidence for supporting the assumption that balance ability predicts better dance performance.

Study 3 (Chapter 6) continues testing postural stability but uses a force plate, examining the effects of possible bilateral differences on dynamic postural stability during single-leg landing using a time to stabilisation protocol (Wikstrom *et al.*, 2005). The Dynamic Postural Stability Index (DPSI) (Wikstrom *et al.*, 2005; Wikstrom *et al.*, 2010) is a functional measure of dynamic postural stability. Importantly, it is an informative measure of neuromuscular control because it calculates single-leg stabilisation movements. It has been suggested that dance training may cause lateral bias (Kimmerle, 2010). There is a dearth of evidence for this assumption, and Mertz and Docherty (2012) found that self-reported leg differences did not correlate with balance ability in jump-landings. This study tests the hypothesis that there would no effect of bilateral differences on postural stability.

Study 4 (Chapter 7) builds on from Study 3 and examines the effects of fatigue using the same time to stabilisation protocol. Fatigue can affect performance with impaired ability to maintain postural stability reducing aesthetic quality of movement (Wild, Grealish and Hopper, 2017). This study tests that assumption and establishes whether these effects might elicit bilateral leg differences. The Dance Aerobic Fitness Test (Wyon *et al.*, 2003) was used as the fatigue intervention.

Study 5 (Chapter 8) develops a novel Accumulation Balance Score designed to gather data on postural stability and postural control in a variety of dance-specific settings, including longer sequences of movement. Uniquely, developing measurements for both postural stability and postural control in one system produces more comprehensive data on these two components of balance, enabling analysis of balance strategies. To date, there are no balance scoring systems designed for application in dance-specific tests including dynamic balances in movement sequences. In addition, the reliability of the Accumulation Balance Score is established. Thus, the aim of this study was to develop a novel balance scoring test for multiple types of testing and to assess interrater and intrarater reliability and validity of the test.

Study 6 (Chapter 9) builds on from the previous studies on balance tests, and examines the effects of balance training on balance ability in a randomised controlled trial. It tests the assumption that dance training alone improves balance. The limited research on balance training of dancers is based on tests used in sport (Hutt and Redding, 2014; Watson *et al.*, 2017; Karim *et al.*, 2019), and it is not known whether more dance-specific or spontaneous improvised tasks might disrupt dancers' normal reactive responses, eliciting greater training effects. Thus, this study compares the effects between in-class improvisation training, supplementary training, and technique training alone (control group). To replicate dance performance more closely, a novel dance sequence is developed to measure postural stability, and tested for reliability. In addition, the ABS (Study 5) was applied to gather data on postural stability and postural control. It was hypothesised that in-class training and supplementary training would not elicit differences in dancers' balance performance.

The final chapter draws the work together in a general discussion of findings and puts forward suggestions as to how the body of work could influence current practice in balance assessment and training and inform future research. Crucially, the final chapter outlines the contribution this PhD has made to the field.

The aim and hypothesis of each study are summarised as follows:

Study 1 (Chapter 4):

Aim: The study was designed to test the associations between five field balance tests which have been viewed as appropriate tools for being employed in previous studies on dancers as revealed in the systematic literature review (Chapter 3).

Null hypothesis: There will be no significant relationships between the five field balance tests.

Study 2 (Chapter 5):

Aim: The study aims to test the assumption that balance ability is associated with dance performance.

Null hypothesis: There is no significant relationship between balance, and ballet, contemporary, and jazz technique competency

Study 3 (Chapter 6):

Aim: To test the assumption that bilateral differences have an effect on postural stability.

Null hypothesis: There is no significant effect of bilateral differences on postural stability.

Study 4 (Chapter 7):

Aim: To test the assumption that fatigue affects bilateral differences on postural stability.

Null hypothesis: There is no significant effect of fatigue on bilateral differences on postural stability.

Study 5 (Chapter 8):

Aim: To develop a novel balance scoring test for assessing postural stability and postural control and to assess interrater and intrarater reliability and validity of the test.

Null hypothesis: There is no significant difference in test-retest scores for the novel balance test.

Study 6 (Chapter 9):

Aim: To examine balance training differences on dancers' dynamic postural stability in a randomised controlled trial.

Null hypothesis: There is no significant effect of in class training and supplementary training on dancers' balance performance.

3 Review of literature

Parts of this chapter have been previously published (Clarke *et al.,* 2018).

3.1 General review of balance and dance

The broad spectrum of research relating to the terms “balance” and “dance” reveals a wide scope of studies which incorporate balance testing, dance interventions and different populations. The word “balance” was employed as it is a term which incorporates postural stability and postural control, as defined earlier in 1.1.1-1.1.3, although these latter terms are not always defined in the studies. The word “dance” in literature searches on balance reveals studies using dance protocols, and different dance genres, as well as research assessing undergraduate and professional dancers, thus both terms enable a comprehensive review of literature in this field. The first part of this general review focuses on literature from a health perspective and comprises of studies using dance interventions with various populations relating to age, and health. Secondly, the general review outlines balance studies on those with dance expertise. This section summarises relevant findings and precedes the systematic review, which crucially, forms the most important part of the review of literature in this chapter and relates specifically to theatrical dance and dancers who are training or professionally working in the field.

In health-related studies, and predominately focusing on fall prevention strategies, the literature on the elderly reveals positive effects on the risk of falls using a range of dance genres as interventions (Fernández-Argüelles *et al.,* 2015). Positive results on balance were found after interventions of dance based exercise programmes (Hui, Chui and Woo, 2009), Tango dance (McKinley *et al.,* 2008), Turkish (Eyigor *et al.,* 2009), Greek (Sofiandis *et al.,* 2009), and Chinese (Wu *et al.,* 2010) traditional dance. Methodological limitations and bias are evident, with some small sample sizes, and inconclusive evidence of the effects of combining dance interventions with other exercise forms (Fernández-Argüelles *et al.,* 2015). In a younger population, break dance increased static balance in nine years-old soccer players (Ricotti and Ravaschio, 2011), Greek traditional dance was found to improve 6-12 years old girls' dynamic balance (Fotios *et al.,* 2013), and a movement education programme had positive effects on pre-school children (Kayapinar, 2010). There is very limited literature on balance and dance in the younger population, possibly due to the constraints of access to younger participants and the continually changing skills level in relation to periods of growth (Kayapinar, 2010).

Health studies on the effectiveness of dance interventions on balance ability are focused on the elderly and predominately those with Parkinson's disease (Hwang and Braun, 2015). The effects of dance interventions have been found to have positive effects on balance for those with Parkinsons disease in a number of studies (Earhart, 2009; Hackney and Earhart, 2010), although the long-term effects are unknown (Earhart, 2009).

In contrast to the aforementioned populations, there is an assumption that dancers have expertise in balance. Theatrical dance is regarded as a physically challenging activity (Koutedakis and Jamurtas, 2004), requiring excellent postural stability and control (Twitchett *et al.,* 2009a). This stability and control must be commensurate with artistic and aesthetic demands of dance performance (Angioi *et al.,* 2009a; Twitchett *et al.,* 2009b), and athletic levels of fitness (Koutedakis, Budgett and Faulmann, 1990; Koutedakis and Sharp, 1999; Angioi *et al.*, 2009b; Twitchett, Koutedakis and Wyon, 2009a; Wyon *et al.,* 2011) for optimal performance (Redding and Wyon, 2003). Postural control is an important component in maintaining symmetry and dancers are required to demonstrate equal postural control of movement on either side (Kimmerle, 2010). However, it has been shown that dancers can counterbalance turning bias and leg preference (Bläsing *et al.,* 2012), which may in turn, help to reduce injury (Koutedakis *et al.,* 1995; Koutedakis, 2000; Twitchett *et al.,* 2010; Allen *et al.*, 2013), and fatigue and incidents of burnout (Koutedakis *et al.,* 1999).

The complexity of coordination in dance movements involves multiple segments of the body (Wilson, Lim and Kwon, 2004) and it has been suggested that control levels of the nervous system take advantage of mechanisms to stabilise posture to change the body organisation efficiently (Thullier and Moufti, 2004). Postural control and fast postural responses are essential for dancers when performing complex virtuoso movements (Hugel *et al,*, 1999; Perrin *et al.,* 2002). One of the most virtuoso movements in dance is the pirouette and ballet dancers were found to have superior skill in stabilising the turning axis (Golomer *et al.,* 2009a). Dancers, like gymnasts, use both quick and slow movements in their repertoire, and often use a small base of support (Grimshaw *et al.,* 2006; Bruyneel *et al.,* 2010; Costa *et al.*, 2013). In addition, many balances in dance relate more to dynamic equilibrium in response to sudden movements such as acceleration, deceleration, and rotation (Golomer *et al.,* 1999a; Tortora and Derrickson, 2006; Hall, 2007).

Testing balance in dancers can increase understanding about their variability in balance performance (Hugel *et al,*, 1999; Schmit *et al.,* 2005) but there are diverse findings in the literature (Thullier and Moufti, 2004; Kiefer *et al.,* 2011; Perrin *et al.,* 2002; Simmons, 2005a; Kuczyński, Szymańska and Bieć, 2011; Ambegaonkar *et al.,* 2013). To date, the task difficulty of balance tests has varied in studies on dancers and it has been suggested that some validated balance tests may not be challenging enough for expert dancers (Stins *et al.,* 2009; Gerbino, Griffin and Zurakowski, 2007).

Tests on balance ability of dancers have employed a number of testing procedures including force plates and field tests, however, many tests were developed initially for sports and general populations. There is no evidence of replicated studies or analysis of relationships between tests. The Star Excursion Balance Test (SEBT) was originally developed as a rehabilitative tool (Gribble *et al.,* 2012) but has been adapted with a number of modifications including the Y Balance Test (Plisky *et al.,* 2009; Ambegaonkar *et al.,* 2016), and a modified SEBT (m/r SEBT) (Wilson and Batson, 2014). One study which utilised a battery of tests including the SEBT, the Balance Error Scoring System (BESS) and the Modified Bass Test of Dynamic Balance (BASS) found mixed results between dancers and non-dancers' balance ability (Ambegaonkar *et al.,* 2013). Other field tests have used a bespoke one-legged stance (Crotts *et al.,* 1996; Schmitt *et al.*, 2005); a modified Romberg test (Rogers, 1980; Richardson *et al.,* 2010); the Biosway^{TM} balance test (Rein *et al.*, 2011); the Airplane test (Richardson *et al.,* 2010); or more complex, dance-specific tasks such as a modified ronds de jambe (Clark and Redding, 2012), and pirouettes (Denardi *et al.*, 2008; Golomer *et al.,* 2009b; Lin *et al.,* 2011).

A number of studies have included vision conditions. It has been argued that dancers develop specialist skills in regulating posture through visual feedback (Schmit, Regis and Riley, 2005; Golomer *et al.,* 2010; Pérez *et al.*, 2014) and yet, dancers' balance ability may decrease more significantly in closed eyes conditions compared to non-dancers (Pérez *et al.*, 2014). This concurs with studies observing greater postural control with more complexity in dancers than other groups (Schmit, Regis and Riley, 2005; Stins *et al.*, 2009; Pérez *et al.*, 2014), possibly due to dancers' flexibility in changing to different demands of postural control (Schmit *et al.,* 2005).

There is a dearth of evidence in assessing dancers' postural stability using dance-specific movements. Pirouette tests have been conducted as previously mentioned, but another important area for consideration for dancers is their balance control during jump-landings. It is assumed that efficient postural stability and control will result in accuracy of movement and reduced risk of injury. One study revealed that female dancers take longer to stabilise than male dancers on two floor conditions (Pappas *et al.*, 2011), whilst the increased depth of midsole thickness of dance shoes decreases dynamic postural stability (Wyon *et al.*, 2013a). Also, dancers revealed superior balance to soccer players in sway index and centre acquisition time (Gerbino, Griffin and Zurakowski, 2007), lower intersegmental co-ordination variability than non-dancers (Jarvis, Smith and Kulig, 2014), but did not have better balance than non-dancers using the Modified BASS Test of Dynamic Balance (Ambegaonkar *et al.,* 2013).

Overall, the literature on balance in dance encompasses a variety of populations and multiple testing conditions. Specifically, studies on the dance population present mixed findings and inconclusive evidence on a range of conditions. Dancers' balance strategies, including neurocognitive control in performance, may result in variability in balances and potentially biased findings. There is a paucity of replication of studies, which infers potential study limitations (Meader *et al.*, 2014), and potential publication bias (Guyatt *et al.*, 2011c). Replication is important as it can give greater validity to results if the findings are the same, or similar, to the original study. If studies are replicated, the findings may be generalised and applied to a wider population. A lack of replication may influence publication bias which is caused by a number of factors including omission of "negative" studies (which can also cause upward bias in estimating effects), unidentified studies in reviews, unreported studies, delay in publication, early reviews with a small number of studies, and reviews restricted to English language journals. This section highlights the key areas in the literature but in order to identify, evaluate, and summarise the findings of relevant studies on a dance population, a systematic review, adhering to PRISMA guidelines, was conducted. PRISMA provides an evidence-based statement and a comprehensive checklist to help authors of systematic reviews (and meta-analyses) reduce the risk of flawed reporting and present as transparent and complete reporting as possible.

3.2 Systematic review

3.2.1 Introduction

Dance, as a theatrical art form, is characterised by high skill levels of balance that are regarded as a fundamental component of dancers' training (Hamilton *et al.*, 1992) and their professional careers (Shick, Stoner and Jette, 1983; da Costa *et al.*, 2013). Dancers are viewed as balance experts who are able to demonstrate difficult balancing activities (Hugel *et al.*, 1999; Lin *et al.*, 2011) possibly due to faster postural responses (Golomer *et al.*, 1999b; Perrin *et al.*, 2002) and enhanced proprioceptive sensitivity (Golomer, Dupui and Monod, 1997; Golomer *et al.*, 1999a; Simmons, 2005a). In light of this, balance needs to be considered in relation to a dancer's individual needs in a training context (Koutedakis and Sharp, 1999).

It has been found that exercise interventions can improve balance indicators in injured dancers (Leanderson *et al.*, 1996; Cloak *et al.*, 2010; Lin *et al.*, 2011; Clark and Redding, 2012). The contribution of sensory inputs on balance has also been studied on dancers (Guidetti and Pulejo, 1996; Golomer, Dupui and Monod, 1997; Hugel *et al.*, 1999; Golomer *et al.*, 1999a; Golomer *et al.*, 1999b; Golomer and Dupui, 2000; Perrin *et al.*, 2002; Simmons, 2005a; Simmons, 2005b; Schmit, Regis and Riley, 2005; Golomer *et al.*, 2010; Krityakiarana and Jongkamonwiwat, 2016). A number of studies have examined the effects of sensory inputs and laterality (Guillou, Dupui and Golomer, 2007; Mertz and Docherty, 2012). Dancers are required to use two sides of their body alternatively in training and this bilateral symmetry is expected in single-leg balances too and can enhance stabilisation (Guillou, Dupui and Golomer, 2007). Furthermore, while some conflicting results have emerged comparing balance ability between dancers and athletes (Perrin *et al.*, 2002; Schmit, Regis and Riley, 2005; Gerbino, Griffin and Zurakowski, 2007), dancers were found to have greater multi-joint coordination in balance activities than untrained participants (Thullier and Moufti, 2004; Kiefer *et al.*, 2011). However, despite their acknowledged balance expertise, dancers have demonstrated less ability in balance skills than non-dancers using basic tests (Perrin *et al.,* 2002; Simmons 2005a; Kuczyński, Szymańska, and Bieć, 2011; Ambegaonkar *et al.*, 2013), although in more complex sensory challenged conditions, dancers have been shown to have superior abilities (Crotts *et al.,* 1996).

A review by Costa and colleagues (2013), examined static and dynamic balance in ballet dancers but, to date, no systematic reviews exist on the relationship between balance and dance performance. Therefore, the aim of this systematic review was to investigate the current state of experimental evidence on the relationship between balance and dance performance, including balance testing, balance training, and performance. Furthermore, the aim of the literature search was to identify all relevant literature on balance and theatrical styles of dance, involving adult participants who were either in full-time dance training or professional.

3.2.2 Methods

Literature search

The reference sources used were the electronic databases MEDLINE, Cumulative Index to Nursing & Allied Health (CINAHL), PubMed, SPORTDiscus, Cochrane, ScienceDirect, and Google Scholar to find publications from January 1980-March 2020. The Medical Subject Heading (MeSH) terms "postural balance", "balance, postural", "musculoskeletal equilibrium", "postural equilibrium" and "dance" or "dancers" were used. Modifications were made to this search as known key texts in the research area were not included in the results using MeSH terms, and this modification was in line with PRISMA statement recommendations (Liberati *et al.,* 2009). A subsequent search used the terms "balance", "postural stability", and "postural control" combined with "dance" using all the aforementioned databases.

A first-stage screening of titles and abstracts was conducted based on balance testing, balance training, and dance; relevant full articles were retrieved for the second-stage screening. Articles were eliminated using set inclusion and exclusion criteria (Figure 3.1). A second researcher from the supervisory team peer reviewed all papers with particular reference to the inclusion and exclusion criteria. The following outlets were hand searched to ensure that all relevant articles were included: *Journal of Dance Medicine & Science* and *Medical Problems of Performing Artists*. The reference list of the only known literature review on balance in dancers (Costa Ferreira, and Felicio, 2013) was searched to ensure that no relevant papers were omitted.

Inclusion and exclusion criteria

Articles were included if they were experimental, referred to theatrical dance forms, involved professional dancers and/or dance students in vocational and university training, and examined balance. There were no language restrictions and retrieved papers in Portuguese and Chinese were translated in full by researchers in dance science with the relevant first language, fluent English, and proven dance/exercise science expertise. Articles were excluded if they were related to recreational dance, competition dance, involved participants aged younger than 17 and/or older than 45 years old. These age groups are more likely to be involved in recreational dance, and mostly fall outside the age range for professional theatrical dance. Editorials, reviews, abstracts, conference proceedings, theses, bulletins and newsletters were also excluded. Eligibility assessment was conducted in an unblinded standardised manner by two researchers; any disagreements were resolved by consensus based on PRISMA guidelines (Liberati *et al.,* 2009).

Quality appraisal

During the first screening, articles were appraised by title and abstract, to be deemed as probably relevant, unknown relevance or irrelevant. Articles that were categorised as probably relevant or of unknown relevance were obtained subsequently as full texts. In the second screening, these texts were examined and included or excluded according to their relevance to the current review aims. All included articles met the following criteria: clearly stated aims, objectives, or hypothesis; clear description of participants with inclusion and exclusion criteria; appropriate, defined methodology, or a cohesive argument for using the methodology with reference to previously published work, or a pilot study; appropriate choice of statistical analysis with probability values; clear discussion of the results with reference to the original aims of the study; limitations of the study noted.

In order to refine the process for the current review, the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) (Guyatt *et al.*, 2011a; Meader *et al.*, 2014) was applied as it provides a system for rating the quality of the evidence and grading the strength of recommendations presented in any studies under review. GRADE's approach to rating quality of evidence begins with the study design and then addresses five reasons to possibly rate the study lower and three reasons to possibly rate the study higher (Balsham *et al.*, 2011). Higher level ratings include randomised trials. The five reasons for lowering the rating are risk of bias, inconsistency, indirectness, imprecision, and publication bias.

3.2.3 Results

The initial search revealed 1,152 articles. From those articles, 494 were duplicates and removed. Subsequently, 501 unrelated articles, 57 age-related articles and 41 health-related articles were also removed. Only 59 articles were judged to be relevant but none of them directly examined balance and performance (Figure 1). Fifty-one articles relating to balance ability, including postural sway and control are presented in Table 3.1. Five articles relating to multi-joint coordination (Thullier and Moufti, 2004; Schmitt, Kuni and Sabo, 2005; Kiefer *et al.*, 2011; Bronner, 2012; Jarvis, Smith and Kulig, 2014) are presented in Table 3.2. Three articles primarily investigating laterality and balance (Lin, Su and Wu, 2005; Guillou, Dupui and Golomer, 2007; Mertz and Docherty, 2012) are presented in Table 3.3.

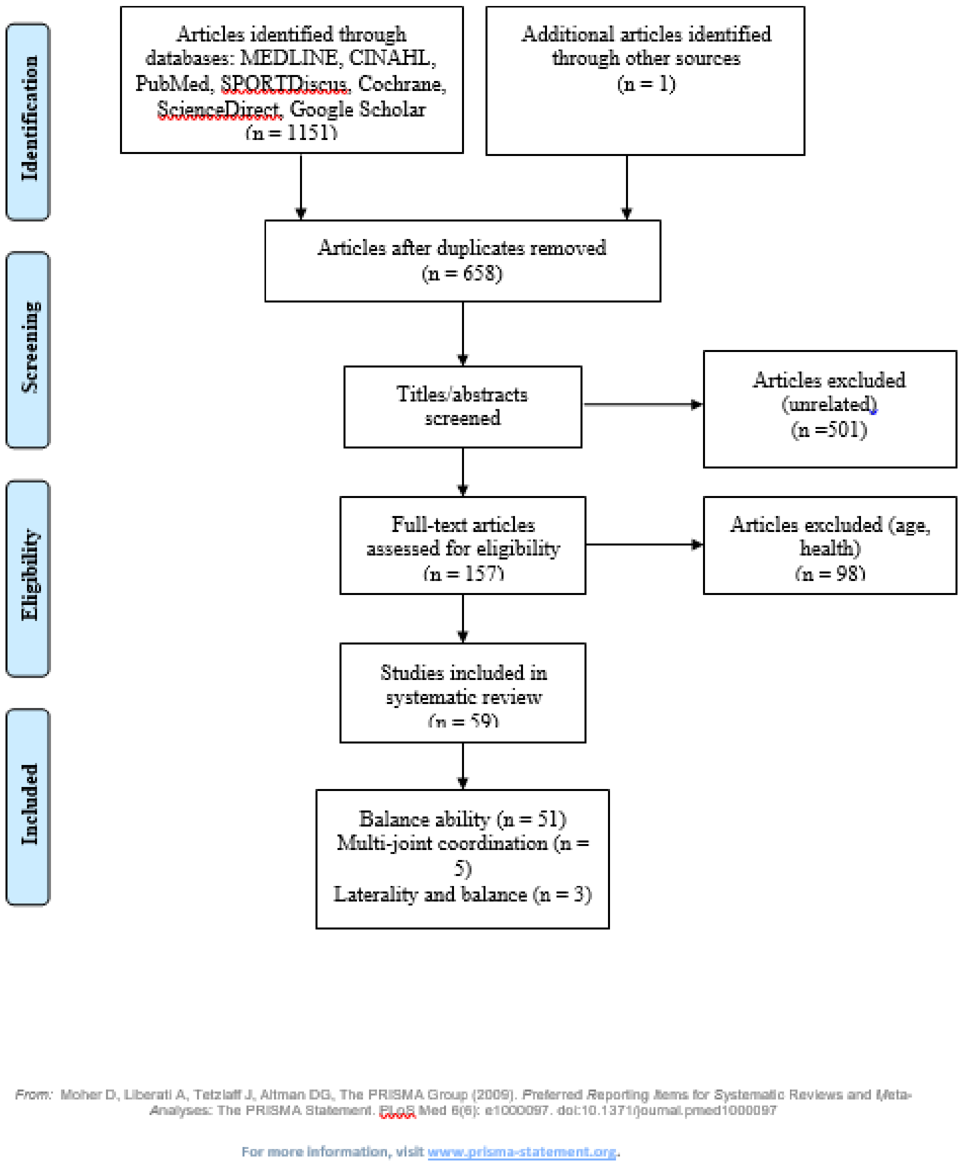

Figure 3.1 Systematic review flow chart

Table 3.1 *Studies primarily investigating balance ability*

Study	Study design	Participants	Method	Outcome	GRADE
Crotts *et al.*, (1996)	Set order of tests following protocol of earlier clinical test	Dancers from Dance Dept, Temple University, USA n=15 (No gender stated) 27±18.3 yrs Non-dancers from PT Dept, Temple University n=15 (no gender stated) 27±16.4yrs	5 x 30second (s) trials of six combinations of visual and support surface conditions in one-legged stance. Modified visual Dome and Foam Test, including eyes open (EO)/eyes closed (EC).	Dancers demonstrated better balance particularly in challenged visual and surface conditions. Dancers employed successful movement strategies to maintain balance.	Low
Golomer *et al.*, (1997)	Experimental	Dancers n=31; 15(M), 16(F) 18.1±0.9yrs (M) 17.4±1.1yrs (F) Acrobats n=23; 11(M), 12(F) 18.8±3.5yrs (M) 17.0±3.0yrs (F) Untrained n=21; 10(M), 11(F) 17.5±2.2yrs (M) 19.7±2.6yrs (F)	Stabilometer; four conditions: two visual (EO/EC), for each of two positions (anteroposterior/lateral equilibrium).	Untrained participants, irrespective of sex, were least stable. Acrobats were more stable than dancers.	Low
Golomer *et al.*, (1999a)	Experimental	Ballet dancers from Paris Opera, France n=30(M): 15 dancers (“quadrilles”) 18.1±0.9yrs 15 dancers (“coryphées”) 23.8±2.2yrs	Stabilometer (“seesaw”); three frequency bands (0-0.5 Hz, 0.5-2 Hz, 2-20 Hz); 4 conditions: standing balance in AP and lateral positions, EO/EC for each position.	Dependency on visual information greatest for 18yr olds possibly due to recent accelerated growth affecting trunk proprioceptive regulation. Higher displacement values for AP position for all groups.	Low

Golomer *et al.*, (1999b)	Experimental	1) Ballet dancers form Paris Opera, France n=13(M) 23.8±2.2yrs Untrained n=10(M) 18.8±3.5yrs 2) Professional dancers n=10(M) n=6 (subgroup for both tests) Untrained n=19(M) 24.5±4.5yrs (whole group)	1)Stabilometer; frequency 0-20 Hz; 4 conditions: standing balance in AP and lateral positions, EO/EC for each position 2) Visual perceptual study using the rod and frame test (RFT); frame tilted at 18˚; tested at 12 different tilts (6R, 6L)	Dancers less dependent on vision for postural control and for perception than untrained. No significant correlation between perceptive visual behaviour (RFT) and dynamic equilibrium performance.	Low
Hugel *et al.*,(1999)	Experimental	Ballet dancers from National Ballet of Nancy and Lorraine, France n=18; 6(M), 12(F) 16-35yrs Nondancers n=46 16-37 yrs	Static posturography using a force platform; two protocols: 1) flat footed, (EO/EC). (2) Bipedal or unipedal balance on demi-pointe (EO/EC for bipedal, & EO for unipedal). Dancers (F): bipedal test on pointe (EO/EC); unipedal on pointe (EO).	Dancers only performed better than controls in EO conditions. Similar results for pointe tests (EO/EC) indicate a learning effect for balances on pointe.	Low
Golomer *et al.*, (2000)	Experimental	Professional dancers of the Opera n=23; 13(F), 10(M) 23.3±6.7yrs (F) 24.1±1.5yrs(M) Untrained n=18; 11(F), 7(M) 19.7±2.6yrs (F) 24.3±3.0yrs (M)	Seesaw; four conditions: two visual (EO/EC), for each of two positions (AP & lateral tilts); angular acceleration measured only for one oscillation plane; two spectral bands: 0-2Hz and 2-20Hz	For lower frequency bands, difference between EO/EC in two positions higher for untrained; higher frequency results showed diff. between EO/EC higher for dancers. (M) dancers used proprioception more than (F) dancers, but performed similarly in dynamic equilibrium tests.	Low
Perrin *et al.*, (2002)	Experimental	Ballet dancers from National Ballet, Nancy & Lorraine, France n=14(F) 22.1±4.5yrs Judoists	Static and dynamic balance tests using a force platform. Static: CFP recorded, (EO/EC).	Only judoists were able to maintain a better balance control than controls in all tests; in EO tests judoists and dancers performed better than controls; in EC, dancers displayed the worst	Low

		n=17(M) 24.8±4.5yrs Nondancers n=42; 21(M), 21(F) 23.9±4.2yrs	Dynamic: slow rotational oscillations, 4˚ amplitude, frequency of 0.5Hz, (EO/EC)	balance control. The combination of EC and a moving support was challenging for dancers.	
Barcellos *et al.*, (2002)	Experimental	Ballet dancers n=4(F) 21.60±1.29yrs	Force plate; motion analysis cameras; parallel balances (20s) EO, en pointe and standing	Sig. diff in AP velocity in pointe position compared to standing.	Low
Simmons (2005a)	Randomised order of tests	Ballet dancers from community dance companies and university n=17(F) 21.4±0.68yrs Untrained n=17(F) 21.6±0.39yrs	Cutaneous foot sensitivity tested with a Semmes-Weinstein monofilament test; dual force plates enclosed by three-sided visual surround; six randomised sensory organisation tests (SOT): SOT 1 & 2 standing (EO/EC), SOT 3 visual surround matched A-P sway of participant's estimated CoG (EO), SOT 4 visual surround stationary but force plates rotated in ref to participant's A-P, SOT 5 same as SOT 4 but EC, SOT 6 both surround and force plates referenced to participant's A-P sway.	No statistical difference in A-P sway between dancers and controls for SOT 1-3; dancers had significantly greater A-P body sway than controls in SOT 4; greater use of hip strategy to maintain balance for dancers in SOT 5 & 6; ballet dancers were significantly less stable in A-P direction during static balance when forced to rely on visual and vestibular input (SOT 4) or vestibular input alone (SOT 5) supporting a notion of a shift in sensory weighting from visual to somatosensory information in ballet dancers.	Low
Simmons (2005b)	Computer-controlled randomised inter-trial-intervals	Ballet dancers from community dance companies and university n=15(F) 21.4±0.76yrs Untrained n=16(F) 21.2±0.47yrs	Dual force plates enclosed by visual surround; force plates rotate upward 8˚ at rate of 50˚ per second; 20 trials of standing balance; EMG electrodes parallel to long axis of medial gastrocnemius and anterior tibialis muscles of each leg.	No significant difference between groups for short-latency (SL) or medium-latency (ML) responses. However, dancers had significantly faster and more consistent long-latency responses than controls.	Low

Schmit *et al.*, (2005)	Randomised order of trials	Dancers from Dance Dept, University of Cincinnati College Conservatory of Music n=10; 5(F), 5(M) 20 yrs (mean) Varsity track team runners, U of C, served as control group n=10; 5(F), 5(M) 19.5yrs (mean)	Force platform; four trials each of four experimental conditions of vision and support in standing balance: EO/rigid; EO/foam, EC/rigid, EC/foam.	Results showed postural sway of dancers was less regular, less stable, less complex and more stationary than that of track athletes. Difference between EO and EC conditions was greater when participants stood on the foam.	Low
Coutts *et al.*, (2006)	Experimental	Contemporary dance students from Northern Rivers Conservatorium and regional dance schools n=9; 6(F), 3(M) 18.8±5.1yrs	Pre- and post-tests consisting of: Subjective Exercise Experience Scale (SEES); five trials of a right-leg flat-footed arabesque on a force plate; GRF variability and CoP calculated; incremental fatiguing dance protocol conducted on all participants; Rate of Perceived Exertion (RPE) conducted during dance protocol.	Stability indices showed arabesques to be inherently instable postures. No changes in the stability indices were observed. This may have been due to rapid recovery during the post-dance protocol SEES completed before the post-dance arabesque trials.	Low
Denardi *et al.*, (2008)	Experimental	Ballet dancers n=8; (F) 18.5±1.7yrs	Two video cameras (frequency 60Hz) were used: one focusing on participants' eyes, the other on their head & shoulders; five trials of a pirouette en dehors from 5th position on L leg support (EO/EC).	Postural stability deteriorated with EC; long initial gaze fixation durations and reduced body oscillations were noted; clear sequencing of trunk, head and gaze was observed in turns, in response to teachers' cues.	Low
Gerbino *et al.*, (2007)	Set test condition order	Collegiate dancers trained in modern dance and ballet n=32(F) 20.3±1.5yrs Soccer players n=32(F) 19.7±1.7yrs	Matscan pressure mat; COP variability; centre acquisition time (CAT) used to quantify ability to "centre"; barefoot unipedal balance (R leg only); three trials each of five test conditions: EO, EC, foam mat, landing from jump, landing from side weight shift (cutting); jump tests: two steps & hop (land R ft);	Overall, dancers scored better in 5 out of 20 measures; in sway index and CAT scores dancers demonstrated better balance; training effect and selection of R leg as test leg suggested as factors; large STD in EC for both groups.	Low

			CAT, sway index, sway velocity and sway path length measured.		
Golomer *et al.*, (2009a)	Set order of trials.	Ballet dancers n=8(F) 19±1.5yrs Untrained n=7(F) 19±1.5yrs	Vividness of Movement Imagery Questionnaire (VMIQ); Vicon 8 system, nine cameras; five trials for each of four types of rotation: left foot clockwise (LCW), left foot counter-clockwise (LCCW), (RCW), (RCCW) EO. Supporting foot displacement measured in pirouettes.	In preferred pirouettes, en bloc shoulder-hip stabilisation demonstrated by dancers but not untrained; in non-preferred turns en bloc not maintained in dancers CCW on L support leg or in any condition by untrained; at end of turns untrained were en bloc for CCW (preferred direction) on both legs.	Low
Golomer *et al.*, (2009b)	Investigators blinded to participants' perceptual styles, but set order of trials to reduce fatigue	Ballet dancers n=10(F) 19±2yrs	Vividness of Movement Imagery Questionnaire (VMIQ); Vicon 8 system, nine cameras; five trials for each of four types of rotation: left foot clockwise (LCW), right foot counter-clockwise (RCCW), (LCCW), (RCW), EO. Sequence repeated EC. Supporting foot displacement measured during the pirouettes.	Kinesthetic (K) dancers demonstrated more SF displacement in the CCW turn than in the CW turn. K dancers showed no significant effect of vision on SF displacement. Visual/Kinesthetic dancers had higher SF displacement with EC. V/K dancers less stable EC, but K dancers had similar stability with EO or EC.	Low
Bruyneel *et al.*, (2010)	Experimental; randomly tested	Ballet dancers n=20; 6(M),14(F) 22.4±5.06yrs	GFRs (AP, ML, V) were recorded on a forceplate (MATLAB v.6) Randomly assigned tests: leg extensions, 45˚, anterior, lateral, posterior; EC/EO.	EC increased AP, ML, and V impulsions. Suggested learning effect for enhanced balance results in adult group, but visual dependence for postural control.	Low
Golomer *et al.*, (2010)	Experimental	Professional ballet dancers n=7(F) 19±1.6yrs Untrained n=7 19±1.3yrs All participants (n=14) were dextral (right handed)	Seesaw platform on top of a force platform; sampling frequency of 40Hz; AP (pitch) and lateral (roll) directions; one-legged balance (L & R); two visual hemifields were isolated, highlighting hemispheric asymmetry (visual target)	In pitch sway, higher instability for all with left visual hemifield suppression. Visual restrictions had no effect on roll stability for untrained. Similar stability for AP sways for all participants. Higher instability for dancers in roll (L) conditions with left visual hemifield suppression; dancers may depend more on vision to maintain equilibrium.	Low

Batson (2010)	Testers were randomised; randomized testing of the m(SEBT)	Dance students from Trinity Laban Conservatoire of M & D, UK (Grp A), and North Carolina School for the Arts, USA (Grp B) Grp A: n=22; 20(F), 2(M) 20.6±1.5yrs Grp B: n=15; 13(F), 2(M) 19.8±1.5yrs	Two tests: Star Excursion Balance Test (SEBT), modified SEBT (mSEBT); modifications were: 1) timed test, (2) timed test with cognitive interference (answering questions), (3) standing on foam pad with self-selected pace.	29 participants completed tests; use of variable strategies used by dancers. Inter- and intra-dancer variability was observed. Foam tests often resulted in dancers' vision shifting downwards & some falls were reported. Factorial analysis of SEBT suggests that some SEBT spokes are redundant.	Low
Cloak *et al.*, (2010)	Randomly assigned groups; randomised order of SEBT reach directions. Intervention study; RCT	Dance students from a university dance department n=38 (F) 19±1.1yrs Assigned as follows: Vibration training group n=19 Controls n=19	Pre-tests, participants completed Cumberland Ankle Instability Tool (CAIT) questionnaire; R Scan pressure mat; two trials of one-legged bare foot stance (EO) measuring COP; three trials of SEBT tested on unstable ankle; EMG demi-pointe stance of 30s; WBVT grp: 6 wk progressive programme of bare foot single leg dynamic exercises (bi-weekly).	Static and dynamic balance significantly improved; significant improvements in SEBT anterior, anterior medial, medial, and anterior lateral for WBVT group; no sig difference in % decrease in mean power frequency (MPF) between groups in demi-pointe stance, but sig. difference in COP between groups..	High
Caplan *et al.*, (2011)	Experimental	Professional dancers from a contemporary dance company n=7; 4(F), 3(M) 32±7yrs	Rotating platform placed on top of force platform; static one-legged balance; single trial; heel of raised leg in contact with support leg and hands on knee of raised leg; stance position and same angular velocity as that used in choreography	Participants able to maintain posture for 66±32 seconds; Six participants showed reductions in A-P and M-L sway; one participant showed a slight increase in A-P and M-L sway. No statistical differences found but reductions in sway showed large effect.	Low
Lin *et al.*, (2011)	Sequences randomised by drawing	Dancers Injured (recent past injury) n=11(F) 19.7±2.4yrs Uninjured n=11(F)	Force plate; centre of pressure calculated; four x 15s trials of each condition: single-leg stance (EO/EC), first position, fifth position, and en pointe; non-dancers: single-leg stance only.	Inj (I) dancers had greater max displacement in ML direction & total trajectory of COP than other two groups. In first and fifth positions (I) dancers demonstrated greater STD of COP in ML and AP directions,	Low

		18.8±3.1yrs Non-dancers n=11(F) 20.0±1.9yrs		compared with (UI) dancers. On pointe, (I) had greater max displacement in ML and AP directions compared with (UI).	
Pappas *et al.*, (2011)	Randomised order of conditions	Dancers n=36; 23(F), 13(M) 28±5 yrs (F) 26±4 yrs (M)	Force plate; three trials of R leg hop on each of the five floor conditions: flat, four inclined (anterior, posterior, medial, lateral); time to stability (TTS) calculated for each landing; data analysed from the first 5s; participants' own athletic shoes.	F dancers demonstrated longer TTS in both directions (A-L, M-L); neither floor inclination or floor x gender had an effect on TTS. Proprioceptive feedback, shoes, and ankle laxity may be factors in the gender differences. Landing on inclined floor did not cause dancers to land with an increased TTS.	Low
Rein *et al.*, (2011)	Randomised order of testing	Professional dancers n=20(F); 10(M) 27±9yrs Amateur dancers n=20(F); 10(M) 34±11yrs Controls n=15(F); 15(M) 31±13yrs	Biodex Stability System (tilting); three test evaluations (EO) were performed for each position condition: Conditions were: with level 2 (unstable) or level 8 (stable), both legs, right leg, and left leg.	Professional dancers showed better overall stability index (OSI), ML, and AP scores than both other groups at both levels and in all standing conditions; they balanced more in the AL and less in the PM part of their feet when compared to amateur dancers and controls.	Low
Clark *et al.*, (2012)	Experimental	Contemporary dance students from a dance conservatoire n=85; 34(M), 51(F) 19.56±2.68yrs (M) 19.16±2.08yrs (F)	Self-reported previous injury information collected; RSscan Footscan pressure pad; two trials of each balance tasks on the R & L leg: (1)one-legged stork test 10s (EC), (2) modified rond de jambe 6s (EO).	Participants exhibited greater postural stability when balancing on L leg; F dancers exhibited greater postural stability than M.	Low
Ambegaonkar *et al.*, (2013)	Randomised order of tests. Reliability and error scores incl.	Dancers (primary form: modern dance) n=18 (F) 20.0±0.8yrs Nondancers n=15 (F) 22.1±2.8yrs	BESS: six conditions, three stances (double leg, single leg, tandem) , two surfaces (rigid floor & foam pad) ; reliability between .50 and .88; (EC) SEBT: three testing directions AM, M, PM; reliability between	Dancers demonstrated better scores than those of non-dancers for BESS, and for the SEBT test directions (M and PM). Dancers did not differ from the non-dancers for the BASS.	Low

			.84 and .92; BASS: alternating leg stance; combination of dynamic & static balance; reliability of .75; alternate jumps marker to marker (total of 10).		
Morrin *et al.*, (2013)	Randomised order of conditions (warm up protocols only)	Contemporary dancers n=10; (F) 27±5yrs	RS foot scan measuring CoP; warm up stretch protocols looking at acute effects on performance indicators including balance; four separate tests of 3 trials of a 5s demi-pointe balance in 5th position.	Dynamic stretch and combination stretch indicated lower CoP movement than static and non-stretch. Balance performance was significantly affected by combination stretch.	Low
Wyon *et al.*, (2013)	Randomised order of conditions	Undergraduate dance students n=28; (F) 19±0.64yrs	Force platform; three trials on R and L leg under four conditions: barefoot, ballet flats (2mm thickness), jazz shoes (7mm), jazz sneakers (30mm); single leg landing in jump protocol taking off from two feet; dynamic postural stability index (DPSI)	Significant differences between midsole thicknesses found for both DPSI and vertical stability (VSI); increased midsole thickness had negative effect on landing stability; greatest increase in instability was the V dimension, and to a lesser extent the ML measurement.	Low
da Costa *et al.*, (2013)	Randomised order of testing	Non-professional ballet dancers n=14(F) 18.4±2.8yrs	Pressure platform; One-legged stance in three ballet poses: attitude devant, attitude derriére, attitude à la seconde; three trials for three ballet poses under two conditions: barefoot (BF) and “slippers”(S)	Smaller COP oscillation areas & AP COP oscillations were produced in BF performances for attitude devant & à la seconde. No sig. differences among ballet poses when performed with (S). Attitude à la seconde produced the smaller COP oscillation areas, lower AP COP oscillations and lower ML velocities than the other poses.	Low
Lin *et al.*, (2014a)	Experimental	Superior experienced ballet dancers(SE) n=9 (F) 18.2±1.0 yrs Experienced dancers (E) n=9(F)	Motion analysis; force plate; single leg stance in retire position beginning and ending in fifth position; three trials for the D and ND leg respectively.	E dancers had better balance when standing on the ND leg; the SE dancers had similar postural stability between legs. SE dancers had a greater maximum COM-COP distance in the AP direction.	Low

		18.3±5.7yrs			
Lin *et al.*, (2014b)	Experimental	Experienced ballet dancers n=13(F) 17.77±3.39yrs	Motion analysis; force plates; five trials of single pirouette en dehors with DL support	Experienced dancers used the translation strategy (maintaining trunk axis vertically) and visual input as a stabilisation strategy	Low
Pérez *et al.*, (2014)	Randomised order of conditions	Undergraduate dancers from the Spanish Royal Conservatory of Dance n=18(F) 23.32±2.58yrs Non-dancers n=30(F) 22.23±1.79yrs	Stabilometer; two conditions (EO and EC); 30s barefoot stance. Complexity of postural sway dynamics calculated by Sample Entropy and Permutation Entropy.	Dancers performed better only in the EO test. Dancers reduced their complexity behaviour in the EC test.	Low
Hopper *et al.*, (2014)	Non-randomised order of tests; randomised order of legs	Professional ballet dancers n=9(no gender listed) 18.78±0.40yrs Pre-professional n=6(no gender listed) 17.00±0.00yrs Recreational n=8(no gender listed) 20.62±0.33yrs	Force plate; total area of COP with 95%CI; 5 single pirouettes on preferred leg; two baseline and post-turn tests on both legs in 10s coup de pied position immediately, 30s and 60s after turn task. Followed by fatigue test: 30s of ballet jumps and repetition of coup de pied tests in 3 time intervals.	No differences between D & ND legs in static balance tests. Prof dancers showed better balance after turns. Fatigue test: no sig. diffs between groups but pre-prof and recreational showed sig. increases in sway.	Low
Li *et al.*, (2014)	Experimental	Professional ballet dancers n=4(F) 18-21yrs	Force plate, EMG, motion analysis cameras; test: 1 pirouette on 1 leg	Ankle & knee strength, & movement control of supp. leg found to be key factors in balance control; core strength and proprioception seen as important in postural control.	Low
Krityakiarana *et al.*, (2016)	Randomised order of tests	Thai classical dancers n=25(F) 21.23±0.46yrs Non-dancer controls n=25(F)	Force plate; mSOT protocol: 3 x 20s trials each of 4 conditions: EO, EC, EO-SS (sway surface), EC-SS; 3 x 20s trials each of 4	Thai dancers had better postural stability then non-dancers with sig. diffs in all tests except the mSOT EO.	Low

		21.16+0.38yrs	conditions: mSOT + DHT (dynamic head tilt)		
Ambegaonkar *et al.*, (2016)	Cross-sectional study design; experimental; set trial order	Collegiate modern dancers n=15(F) 18.3+0.5yrs	SEBT (Y-balance components); three trials each of anterior, posteromedial, & posterolateral reaches on R & L leg.	LE hypermobility and balance showed moderate to good positive correlation.	Low
Casabona *et al.*, (2016)	Randomised order of tests	Professional ballet dancers n=10(F) 23.7+2.5yrs Untrained n=10(F) 27.6+3.5yrs	Force platform; five trials of 30s each for five stances: parallel (10cm), parallel (20cm), extra-rotation (15cm & 20˚ rotation), "duck" (140˚ rotation), tandem.	Sig. differences shown between groups for the "duck" stance (familiar to dancers). Benefit from ballet limited to specific foot configuration.	Low
Kilroy *et al.*, (2016)	Randomised test order	College dancers n=7(F) 18-23yrs College non-dancers n=7(F) 18-23yrs	Force plate; three trials of 30s for each of four single-leg stance conditions: DL support with athletic shoe (S), DL support barefoot, NDL support (S), NDL support (BF).	Between groups, non-dancers were more unstable with sig diffs in AP & ML GRF, & balance time. Within groups, dancers were more unstable on NDL (S & BF).	Low
Zaferiou *et al.*, (2016)	Participants selected the order of turns	Professional & pre-professional ballet & contemporary dancers n=10(F) 20.40+3.17yrs	Forceplates; motion capture system; between 5-7 trials per turn condition: piqué en dedans (single & double), pirouette en dehors (s & dble); self-selected ballet shoes & stance limb.	COM more vertically aligned with BoS in pirouette than piqué. RFs were regulated relative to the COM as rotational demands increased in both turns.	Low
Park *et al.*, (2016)	Experimental	Dancers n=6(F) 26.33+1.72yrs Non-dancers n=6(F) 23.33±3.67yrs	In-house perturbator equipment with waist pull; three intensities (low, moderate, high); stability measured by margin of stability (MoS) & time to contact (TtC); double-leg stance.	Dancers more had greater MoS and longer TtC values than non-dancers with sig.diffs at moderate intensity only.	Low
Costa de Mello *et al.*, (2017)	Tests randomly repeated	Ballet dancers n=14; 12(F), 2(M)	Force plate; CoP calculated; two tests, three trials each: (1) single	Dancers showed greater postural sway than non-dancers in EC test, and visual	Low

		28.4±10.8yrs Non-dancers n=14; 12(F), 2(M) 28.7±10.7yrs	leg stance (EO/EC), 35s; (2) passé on demi-pointe (EO), 20s, for dancers only.	afferent is important contributor to better regulation of postural balance; demi pointe caused increase in sway velocity when compared to single leg EO test.	
Martin-Sanz *et al.*, (2017)	Prospective study	Ballet dancers from Dance Conservatory of Madrid & Intl Sch of Dance, Madrid n=40(F) 26.1±1.8yrs Non-dancers n=38(F) 24.3±2.2yrs (NB:Vestibular neuritis patients data not included)	Computerised dynamic posturography carried out with 6 sensory organisation tests (SOT): SOT 1 & 2 standing (EO/EC), SOT 3 visual surround move matching A-P sway of participant's movements (EO), SOT 4, 5 & 6-same visual surround as SOT 1, 2 & 3 respectively, but in each, the A-P sway of the participant drives movement of support surface in axis parallel to ankle joint, referenced to participant's A-P sway.	Dancers had significantly greater AP sway than non-dancers in SOT 5 & 6, but there were no significant differences in AP sway between the two groups for SOT1-4. There were no significant differences in postural stability between dancers and non-dancers.	Low
Sirois-Leclerc *et al.*, (2017)	Experimental; randomised trials	Undergraduate and graduate contemporary dancers from School of Dance, Ottawa n=20; 17(F), 3(M) 23±3yrs Non-dancers n=16; 13(F), 3(M) 22±2yrs	Baseline measures of cognitive tasks (s) (1) simple reaction time (SRT) & (2) choice reaction time (CRT) responses taken on force plate; CoP recorded in postural stability tests on force plate; total of 24 postural task trials (4 trials for each direction): 8 x w/out reaction times (4 x AP & 4 x ML), 8 x with SRT (4 x AP-SRT & 4 x ML-SRT), 8 x with CRT (4 x AP-CRT & 4 x ML-CRT).	Dancers were able to control COP movement during dynamic tracking task in the ML and AP direction, whereas non-dancers' performance decreased for the ML direction. The dancers' ability was evident in the tracking task alone or combined with a SRT task, but lost when the tracking task was combined with a CRT task. The increased ability may depend on attentional resources.	Low
Marulli *et al.*, (2017)	Experimental	Collegiate modern dancers n=11 Pre-professional ballet dancers	Single-limb stance test on each leg; (EC) and measured in (s) up to 60s. (Hypermobility status	Collegiate modern dancers had significantly lower balance times than professional ballet dancers. There were	Low

		n=16 Professional ballet dancers n=45 (NB: younger participants' data not shown)	assessed via Beighton-Horan Laxity test).	no significant differences between balance times of professional dancers and pre-professional dancers or between pre-professional dancers and modern dancers. Hypermobility had no effect on balance.	
Michalska *et al.*, (2018)	Experimental	Ballet dancers n=13 (F) 28±7yrs Non-trained n=13(F) 23±3yrs	Force plate, 100Hz sampling frequency; used rambling-trembling & sample entropy analyses in COP data processing; two trials: (1) quiet standing (QT) double-leg stance (EO/EC), (2) limits of stability (LOS) first 10s-QT stance, then lean as far as fast as possible and maintain position (LOS) until end of test; LOS test sequentially in two directions: forward & backward; QS & LOS trails repeated x 3 with duration of 30s.	Dancers had larger postural sway than non-trained controls; dancers had a greater variability of trembling component in both tests, possibly due to higher capacity to deal with disturbance. Results indicate dancers' postural control is dependent on visual information. Sample entropy results confirm dancers have more automated postural control.	Low
Tekin *et al.*, (2018)	Randomised controlled trial	Undergraduate modern dancers n=33; 24(F), 9(M) 22.39±3.13yrs	Tests: Static passé relevé (EO) and passé flatfoot (EC), airplane, monopodalic-straight and monopodalic-transverse tests. Dominant leg was gesture leg. Monopodalic tests on Libra balance board. All tests repeated x 3 except airplane repeated once. Proprioception neuromuscular group (PNG) did 8-wk training intervention (2 days/wk, 60m/day). This incl. battery of balance, strength & resistance training.	PN group showed significant differences in all tests. Kinesio Tape group (KTG) showed significant differences for airplane and both monopodalic tests (small ES), and control group the airplane (small ES).Between groups, significant differences between PNG and KTG in airplane, passé flatfoot (EC), and between PNG and CG in all tests.	High

Paris-Alemany *et al.*, (2018)	Transversal observational design	Dancers from Superior Dance Conservatory, Madrid (ballet, contemporary, Spanish, Flamenco) n=22; 19(F), 3(M) 24.05±5.74yrs Non-dancers n=22; 15(F), 7(M) 24.27±5.78yrs	mSEBT, 3 directions: ANT, PL & PM [Y]; followed standardised protocol 3 x trials.	Dancers showed higher values in anterior and posterolateral directions (R leg) and anterior (L leg)	Low
Armstrong *et al.*, (2018)	Experimental	Undergraduate contemporary dancers n=35; 30(F), 5(M) 20.09±0.97yrs (F) 20.62±2.43yrs (M)	SEBT, 3 directions: ANT, PL & PM [Y]; randomised order of legs (dom and non-dom); fatigue intervention: Dance Aerobic Fitness Test (DAFT).	Results showed no significant effect of fatigue on SEBT performance. Dancers may have used performance adaptations and balance strategies.	Low
Janura *et al.*, (2019)	Experimental	Ballet dancers n=25; 12(F), 13(M) 25.6±3.8yrs (F) 23.4±4yrs (M) Non-dancers n=25; 14(F), 11(M) 24.7±2.6yrs(F) 23.6±1.6yrs (M)	Force platform, sampling frequency 200Hz; four unipedal tests (both legs): (1) standing (EO), (2) standing (EC), (3) standing on foam mat (EO), and (4) standing (EO) after performing 10 x 360° turns.	Dancers only had less postural sway and COP velocities than the controls during standing after 10 turns. Even with EO on both types of surfaces, dancers could not utilise their balance training. No gender differences were shown except for controls (M) who had a significantly larger postural sway & higher COP velocity after 10 turns compared to controls (F).	Low
Karim *et al.*, (2019)	Randomised controlled trial	Professional contemporary dancers n=59 (F) 25.78±3.78yrs	Used two balance tests: (1) SEBT x 3 trials, (2) BESS x 1 trial. Followed by a 75s WBV intervention (4 randomly assigned WBV conditions), then immediately after the SEBT & BESS again.	The 75s use of 30Hz WBV frequency (static & dynamic demi-plié) improved static balance. When effect of position, but not frequency, was analysed, for the SEBT, there was significant increase in dynamic balance for both positions; analysis of effect of position for the BESS showed no significant improvement in static balance.	High
Bharnuke *et al.*, (2020)	Experimental	Indian classical dancers n=36 (F)	SEBT, 3 directions: ANT, PL & PM [Y]; 3 trials on both legs;	Dancers demonstrated better balance performance in all tests than non-	Low

	21.75±1.75yrs Non-dancers n=36 (F) 21.75±1.73yrs	Force plate & Vicon motion capture used for various conditions of stance: wide BoS & single-leg with EO/EC & dual task in bipedal & unipedal stance; 3 trials for each condition; Stroop test used in dual task in bipedal stance; rhythmic shoulder movements (similar to Indian classical dance) used in dual task, unipedal.	dancers. Dancers who received more dance training per week showed better balance in the single leg dual task.

Table 3.2 *Studies investigating multi-joint postural coordination*

Study	Study Design	Participants	Method	Outcome	Grade
Thullier *et al.*, (2004)	Experimental	Elite ballet dancers n=6 (no gender described) Gymnasts n=6	Motion analysis; Participants drew single ellipse with R or L foot tip in horizontal plane; ballet shoes worn; orthogonal projections of angular rotation of thigh and shank	Dancers & gymnasts were equally stable. Dancers were more successful in reproducing orientation & shape of the referent ellipses.	Low
Schmitt *et al.*, (2005)	Experimental	Dancers in State Academy n=42; 31(F), 17.6±2.1yrs 11(M), 18.5±1.8yrs Untrained n=40; 29(F), 19.1±3.0yrs 11(M), 20.6±3.6yrs	One-legged standing test barefoot on a mat; conditions: 1m on one leg EO, three trials of 1m balance on alternate legs EC; repeated after 5 months.	Dancers exhibited better balance than the untrained controls. There was no further enhancement in the dancers' performance after five months.	Low
Kiefer *et al.*, (2011)	Experimental	Professional ballet dancers n=28; 10(M), 18(F) 23.59±3.99yrs Untrained n=28; 10(M), 18(F) 23.39±4.99yrs	One-legged balance whilst tracking computer-generated visual target with head; R or L leg; low frequency (0.2Hz) and high frequency (0.6Hz). Four trials (one per condition).	Dancers exhibited less variable stable ankle-hip coordination, and a less deterministic ankle-hip coupling compared to controls.	Low
Bronner (2012)	Experimental	Pre-professional dancers Expert: n=9; 5(M), 4(F) 24.9±1.0yrs Advanced: n=9; 2(M), 7(F) 19.6±0.5yrs Intermediate: n=9; 4(M), 5(F) 19.8±0.5yrs	Motion analysis system; six trials with R leg as gesture limb in a développé arabesque (90˚) protocol.	Differences found in postural pelvic control and intra- and inter-limb coordination. Intermediate (INT) group showed more variability in both dynamic and static postural control than either the Advanced (ADV) group or the Expert (EXP) group.	Low

Jarvis *et al*., (2014)	Experimental	Professional dancers n=10(F) 27.1+3.5yrs Non-dancers n=10(F) 24.8+2.2yrs	Motion analysis system; force plates; 20 consecutive bipedal jumps; rate of 95bpm;	Dancers had lower intersegmental coordination variability than non-dancers for LE sagittal, frontal, & transverse plane couplings, & sagittal plane trunk couplings.	Low

Table 3.3 *Studies investigating laterality and balance*

Study	Study Design	Participants	Method	Outcome	Grade
Guillou *et al.*, (2007)	Randomised experimental conditions	Dancers from Paris Opera n=7(M); 18±0.8yrs Acrobatic gymnasts n=9(M); 19.1±3.6yrs Prof soccer players n=10(M); 17.1±1.1yrs Untrained n=10(M); 21.4±5yrs	Seesaw platform; four conditions: support leg (R & L), and pitch & roll directions; single-leg stance; two frequency bands (0-2Hz & 2-20Hz).	Results for frequency band only significant in roll direction; results showed lateral body balance more important to regulate than AP in a dynamic condition. Physical expertise reduced the dependence on visual &/or vestibular information in roll direction. Soccer players' asymmetrical equilibrium training led to sensorial reorganisation of the L support leg, minimising role of proprioception.	Low
Mertz *et al.*, (2012)	Randomised order of tasks	Ballet dancers from university n=30; 23(F), 7(M) 19.6±1.1yrs	Force plate; three trials each of four bipedal jump tests: landing L foot front, landing R foot front, entrechat trois (jump with a beat) landing on R foot, entrechat landing on L foot; ballet shoes worn; laterality questionnaire.	No diffs. found between preferred leg and non-preferred leg; AP sway and ML sway represent slightly different motions within the foot in AP and ML directions due to use of turn out in feet positions. No diffs. found in postural sway (AP and ML).	Low
Lin *et al.*, (2005)	Experimental	Ballet dancers n=13 (gender not stated but assumed F) 19.15±1.9yrs	Motion analysis system; force platforms; one of three 1s trials in static first position and three of five 5s trials of relevé en pointe were analysed.	Similar ROM & excursion patterns but diff. initial moment exertions on D & ND sides & sig diffs in peak moments. D side had a greater moment range thus likely to be primary controller of balance.	Low

Of the 59 relevant papers, only three included a random controlled trial (RCT) (Cloak *et al.,* 2010; Tekin *et al.,* 2018; Karim *et al.,* 2019) and achieved a high GRADE score. These studies were also the only ones to include interventions. The remaining studies were experimental without randomisation or pre-experimental and thus rated as a low score under GRADE recommendations. Small sample sizes were common, and imprecision on participants' gender (Crotts *et al.,* 1996; Thullier and Moufti, 2004; Lin, Su and Wu, 2005; Hopper *et al.,* 2014; Marulli *et al.,* 2017) and age SD (Schmit, Regis and Riley, 2005; Hugel *et al.,* 2007; Kilroy *et al.,* 2016; Marulli *et al.,* 2017) further weakened the evidence (Guyatt *et al.,* 2011b; Guyatt *et al.,* 2011c).

The inclusion criteria were fairly limited and often just compromised of the number of years of training and ability level. Although 22 papers used the term "randomised" in their study design this related to the order of test conditions, legs, sequences, and testers. A set order of tests was common and in general, no reason was given for this, although Golomer and colleagues (2009b) stated an aim of reducing fatigue. Despite these limitations, studies demonstrated probability values of $p<0.05$ and a clear discussion of the results. Overall, the 59 articles demonstrated a breadth of participants, measuring tools, and research topics in their studies, which reflects the current early stages of research in balance and dance.

Participants

Of the 59 papers, 33 articles included ballet dancers (Hugel *et al.,* 1999; Golomer *et al.,* 1999a; Golomer *et al.,* 1999b; Golomer and Dupui, 2000; Barcellos and Imbiriba, 2002; Perrin *et al.,* 2002; Thullier and Moufti, 2004; Lin, Su and Wu, 2005; Simmons, 2005a; Simmons, 2005b; Schmit, Regis and Riley, 2005; Gerbino, Griffin and Zurakowski, 2007; Guillou, Dupui and Golomer, 2007; Denardi, Ferracioli and Rodrigues, 2008; Golomer *et al.,* 2009a; Golomer, Gravenhorst and Toussaint, 2009b; Bruyneel *et al.,* 2010; Golomer *et al.,* 2010; Kiefer *et al.,* 2011; Mertz and Docherty, 2012; da Costa *et al.,* 2013; Hopper *et al.*, 2014; Lin *et al.,* 2014a; Lin *et al.,* 2014b; Li *et al.,* 2014; Casabona *et al.,* 2016; Zaferiou, Wilcox and McNitt-Gray, 2016; Costa de Mello, Ferreira and Felicio, 2017; Martin-Sanz *et al.,* 2017; Marulli *et al.,* 2017; Michalska *et al.,* 2018; Paris-Alemany *et al.,* 2018; Janura *et al.,* 2019), fourteen contemporary/modern dancers (Coutts *et al.,* 2006; Gerbino, Griffin and Zurakowski, 2007; Caplan and Gibson, 2011; Clark and Redding, 2012; Ambegaonkar *et al.,* 2013; Morrin and Redding, 2013; Zaferiou, Wilcox and McNitt-Gray, 2016; Ambegaonkar *et al.*, 2016; Sirois-Leclerc, Remaud and Bilodeau, 2017; Marulli *et al.,* 2017; Tekin *et al.,* 2018; Paris-Alemany *et al.,* 2018; Armstrong *et al.,* 2018; Karim *et al.,* 2019), one included Thai dancers (Krityakiarana and Jongkamonwiwat, 2016), one included Indian classical dance (Bharnuke, Mullerpatan and Hiller, 2020), one included Spanish dance and Flamenco (Paris-Alemany *et al.,* 2018), six included other expert athletes in an additional test group (Golomer, Dupui and Monod, 1997; Perrin *et al.,* 2002; Thullier and Moufti, 2004; Schmit, Regis and Riley, 2005; Gerbino, Griffin and Zurakowski, 2007; Guillou, Dupui and Golomer, 2007), 25 involved untrained participants (controls), and 14 comprised of dancers whose genre expertise was unspecified. Of the selected papers, 50 examined female participants, 25 examined males while five papers did not specify the gender of participants.

Testing procedures

Overall, the selected studies demonstrated a variety of testing procedures (Tables 3.1-3.3): 29 used force plates as the principal apparatus for testing balance (Hugel *et al.*, 1999; Barcellos and Imbiriba, 2002; Perrin *et al.*, 2002; Lin, Su and Wu, 2005; Schmit, Regis and Riley, 2005; Simmons, 2005a; Simmons, 2005b; Coutts *et al.,* 2006; Bruyneel *et al.,* 2010; Golomer *et al.,* 2010; Caplan and Gibson, 2011; Lin *et al.,* 2011; Pappas *et al.,* 2011; Mertz and Docherty, 2012; Wyon *et al.,* 2013a; Hopper *et al.,* 2014; Jarvis, Smith and Kulig, 2014; Lin *et al.,* 2014a; Lin *et al.,* 2014b; Li *et al.,* 2014; Casabona *et al.,* 2016; Kilroy *et al.,* 2016; Krityakiarana and

Jongkamonwiwat, 2016; Zaferiou, Wilcox and McNitt-Gray, 2016; Costa de Mello, Ferreira, and Felicio, 2017; Sirois-Leclerc, Remaud and Bilodeau, 2017; Michalska *et al,* 2018; Janura *et al.,* 2019; Bharnuke, Mullerpatan and Hiller, 2020), 11 studies employed motion capture analysis (Thullier and Moufti, 2004; Lin, Su and Wu, 2005; Denardi, Ferracioli and Rodrigues, 2008; Golomer *et al.,* 2009a; Golomer, Gravenhorst and Toussaint, 2009b; Bronner, 2012; Jarvis, Smith and Kulig, 2014; Lin *et al.,* 2014a; Lin *et al.,* 2014b; Li *et al.,* 2014; Bharnuke, Mullerpatan and Hiller, 2020), seven studies used the stabilometer, sometimes referred to as a "seesaw" (Golomer, Dupui and Monod, 1997; Golomer *et al.,* 1999a; Golomer *et al.,* 1999b; Golomer and Dupui, 2000; Guillou, Dupui and Golomer, 2007; Pérez *et al.,* 2014), and placed on a force plate (Golomer *et al.,* 2010), five studies utilised a pressure mat (Gerbino, Griffin and Zurakowski, 2007; Cloak *et al.,* 2010; Clark and Redding, 2012; da Costa *et al.,* 2013; Morrin and Redding, 2013), eight studies included the SEBT or modified versions: SEBT (Batson, 2010; Cloak *et al.,* 2010; Ambegaonkar *et al.,* 2013; Karim *et al.,* 2019), the modified SEBT (Batson, 2010; Paris-Alemany *et al.,* 2018), the Y-balance (SEBT components) (Ambegaonkar *et al.,* 2016; Armstrong *et al.,* 2018; Bharnuke, Mullerpatan and Hiller, 2020). Other assessment tools included the Balance Error Scoring System (BESS) (Ambegaonkar *et al.,* 2013; Karim *et al.,* 2019), the modified Bass Test of Dynamic Balance (BASS) (Ambegaonkar *et al.,* 2013), a goniometer and computer generated visual target (Kiefer *et al.,* 2011), a Rod and Frame Test (RFT) (Golomer *et al.,* 1999b), a Biodex System (Rein *et al.,* 2011), a Foam and Dome Test (Crotts *et al.,* 1996), a balance board (Tekin *et al.,* 2018), an observed timed-measure (Schmitt, Kuni and Sabo, 2005; Marulli *et al.,* 2017, Tekin *et al.,* 2018), an in-house perturbator (Park *et al.,* 2016); a Stroop test (Bharnuke, Mullerpatan and Hiller, 2020), and computerised dynamic posturography (Martin-Sanz *et al.,* 2017).

Whilst most studies employed quite basic balance tasks, a number of tests used dance-specific, complex balance tasks. Turns were regarded as a challenging balance activity (Lott and Laws, 2012) and seven studies tested balance using pirouettes (Denardi, Ferracioli and Rodrigues, 2008; Golomer *et al*., 2009a; Golomer, Gravenhorst and Toussaint, 2009b; Hopper *et al.,* 2014; Lin *et al.,* 2014b; Li *et al.,* 2014; Zaferiou, Wilcox and McNitt-Gray, 2016). These studies covered a range of research questions including control strategies on two types of turn (Zaferiou, Wilcox and McNitt-Gray, 2016), leg stability and trunk strategies for ballet dancers and untrained participants (Golomer *et al.,* 2009a), and the relationship between visual information and postural control including gaze fixation in turns (Denardi, Ferracioli and Rodrigues, 2008). Four studies used balance tasks en pointe (balancing on the tips of the toes in reinforced pointe shoes) (Hugel *et al.*, 1999; Barcellos and Imbiriba, 2002; Lin, Su and Wu, 2005; Lin *et al.*, 2011), four included a complex balance position namely: arabesque (Pappas *et al.,* 2011; Bronner, 2012), attitudes (da Costa *et al.*, 2013), and retiré (Lin *et al.,* 2014a) and one study included beaten jumps (legs cross in mid-air) (Mertz and Docherty, 2012) (see Tables 3.1-3.3)

Vision conditions

The total of 27 papers adopted specific vision conditions in their testing. Visual input was viewed as important for postural control and dancers demonstrated better balance ability in eyes open conditions (Hugel *et al.,* 1999; Bruyneel *et al.,* 2010) and eyes closed conditions (Tekin *et al.,* 2018). Other studies (Perrin *et al.,* 2002; Simmons, 2005a; Janura *et al.,* 2019) found no differences between dancers and controls in eyes-open conditions. In closed eyes conditions, dancers have found it harder to maintain postural control than non-dancers (Hugel *et al.,* 1999; Perrin *et al.,* 2002) or had less visual field-dependency than non-dancers (Golomer *et al.,* 1999b).

Multi-joint coordination

Six articles focused on multi-joint coordination in relation to balance ability (Table 3.2). Dancers were more successful in reproducing the orientation and shape of an ellipse than novices (Thullier and Moufti, 2004). Comparing dancers to non-dancers, Kiefer and colleagues (2011) found that expertise did not seem to play a role in adoption of coordination patterns. Schmitt, Kuni and Sabo, (2005) found that ballet training alone does not lead to improvements in ankle joint position or improved measures of balance. Differences were found in postural pelvic control and intra- and inter-limb coordination (Bronner, 2012), and the less experienced group showed more variability in both dynamic and static postural control than the more advanced students and professional dancers. Jarvis, Smith and Kulig, (2014) reported that dancers had lower intersegmental coordination variability than non-dancers for LE sagittal, frontal, transverse plane couplings, and sagittal plane trunk couplings.

Laterality

Three articles focused on laterality and balance (Table 3.3), two based on testing solely dancers (Lin, Su and Wu, 2005; Mertz and Docherty, 2012), whilst a study by Guillou, Dupui and Golomer (2007) assessing dancers, acrobats and soccer players, found that soccer players' asymmetrical equilibrium training led to a sensory organisation of their left support leg. Dance training is regarded as symmetrically based as dancers are expected to perform movements with equal proficiency on both sides; this is reflected in codified training, and yet dancers often perceive a preferred "stronger" leg. Examining the relationship between postural stability and self-reported leg preferences, Mertz and Docherty (2012) found no difference between the preferred leg and the non-preferred leg and the perceived heightened balance ability on one leg did not manifest itself in actual heightened balance ability in two-legged stance or one-legged stance. Lin and colleagues (2005) found that the dominant side had a greater moment range than the non-dominant range and proposed that the dominant side was the primary controller of balance in a dance movement. There were variations in the identification of the dominant leg. Two studies identified the dominant leg as the preferred leg in a dance-specific movement (Mertz and Docherty, 2012; Lin, Su and Wu, 2005) which supports the complexity of lateral bias in dance such as ballet (Kimmerle, 2010), whereas Guillou and colleagues (2007) were similar to other studies in the review (Pappas *et al.,* 2011; Lin *et al.,* 2014a) identifying the dominant leg as the preferred leg kicking an object, although this is not a dance-specific skill (Kimmerle, 2010).

3.2.4 Discussion

The aim of this systematic review was to evaluate the evidence for the relationship between balance and dance performance, including balance testing, balance training and performance. By applying GRADE recommendations (Guyatt *et al.*, 2011a), only three studies were detected as having an RCT design (Cloak *et al.*, 2010; Tekin *et al.*, 2018; Karim *et al.*, 2019). Only these studies incorporated an intervention out of the 59 chosen articles. The remaining 56 studies demonstrated low scores and lacked precision in their methodology (Guyatt *et al.*, 2011b; Guyatt *et al.*, 2011c). The limited number of RCTs indicates the current low level of research in dance; the latter has also been confirmed by others (Amorin *et al.*, 2015). In addition, several studies were pre-experimental with only one group and/or no controls and these factors reflect poor methodology and an increased risk of bias (Liberati *et al.*, 2009; Balsham *et al.*, 2011). The wide range of study designs across 59 articles demonstrates a lack of replication in this field.

Task difficulty

A variation of balance tasks was employed by different research groups. Some of the standing balance tasks were found to be easy to maintain by dancers (Schmitt, Kuni and Sabo, 2005; Casabona *et al.*, 2016), whereas Hugel and colleagues (1999) found that not all their dancers could perform the set tasks on pointe. The eyes open (EO) standing balance tasks on stable floor conditions in tests may create a biased effect as they generate little demand on balance abilities of dancers. In studies with complex dance-specific balance tasks, researchers need to be rigorous in gaining knowledge of the dancers' abilities before the start of the testing process so that the risk of bias is minimised.

Vision and stability conditions

Some dancers found vision and stability conditions increased the level of task difficulty (Perrin *et al.,* 2002; Simmons, 2005a) although the results were variable with some dancers showing poor balance in the least challenging tasks (Krityakiarana and Jongkamonwiwat, 2016; Janura *et al.,* 2019). A shift from visual information to greater dependence on somatosensory information in dance training has been suggested (Golomer and Dupui, 2000), and this is supported by a later study which found that dancers were less stable when somatosensory information was made unreliable (Simmons, 2005a). Dancers often train in front of a mirror and have spatial references in rehearsals and on stage and thus, struggle when those references are unavailable (Hugel *et al.,* 1999; Golomer *et al.,* 1999a; Golomer and Dupui, 2000; Schmit, Regis and Riley, 2005).

It has been suggested that dancers need to rely more on proprioception on stage as the stage lights are dazzling and nothing can be seen in the auditorium (Golomer *et al.,* 1999a). Tests on proprioception found that dancers relied on a greater proprioceptive input than nondancers, particularly when tested at a higher frequency band (2-20Hz) on a stabilometer which has been shown to indicate the contribution of proprioception to postural control (Golomer and Dupui, 2000). Age and physiological maturity was suggested as a factor when assessing vision and equilibrium in a number of articles by Golomer and colleagues (1997; 1999a) who noted that 18 years old male students were more vision dependent than their female counterparts, due to a temporary deficiency in the trunk proprioceptive regulation caused by their growth acceleration. Protocols, used in the listed studies, may complicate data evaluation, such as those from vision studies (Hugel *et al.,* 1999).

Dance-specific balance tasks

There were a variety of research outputs using complex dance-specific balance tasks. For example, Lin *et al.,* (2014b) found that experienced dancers utilised translation strategies, whilst Hopper *et al.,* (2014) noted that dancers had better balance after turns than non-dancers. Further replication of the studies using dance-specific tasks, and the inclusion of interventions and RCTs would strengthen the data. Small sample sizes in dance-specific studies constituted a further limitation.

Adjustments in balance

Studies investigating multi-joint coordination reported less variability in intersegmental coordination (Jarvis, Smith and Kulig, 2014) and ankle-hip coordination (Kiefer *et al.,* 2011) in dancers except for a jump prelanding stage (Jarvis, Smith and Kulig, 2014). Superior neuromuscular control may be indicated by less variability in the trunk and adjustments in balance (Schmitt, Kuni and Sabo, 2005; Bronner, 2012; Jarvis, Smith and Kulig, 2014). Some studies on laterality reported that leg preference did not affect balance in jump landings (Mertz and Docherty, 2012) or unipedal stance, even if enhanced symmetrically (Guillou, Dupui and Golomer, 2007) concuring with other findings (Koutedakis, Stavropoulos and Metsios, 2005).

Several studies examined in this review compared balance abilities between dancers and athletes. Different dynamic patterns were found in dancers compared to track athletes (Schmit, Regis and Riley, 2005), whilst dancers demonstrated better balance than soccer players in certain tests including a greater ability to gain centre after perturbation (Gerbino, Griffin and Zurakowski, 2007). In eyes open tests, judokas and dancers performed better than controls, but only judokas were able to maintain a better balance than controls in all the tests (Perrin *et al.,* 2002). Different training strategies, physical and artistic demands, as well as different testing conditions may have affected the results.

Foot and shoe conditions

The studies used herein adopted a range of foot and shoe conditions in their protocols, such as barefoot (Gerbino, Griffin and Zurakowski, 2007), ballet shoes (Lin *et al.,* 2011), a range of barefoot/shoe conditions (da Costa *et al.,* 2013; Kilroy *et al.,* 2016), and two studies used athletic shoes (Pappas *et al.,* 2011) and jazz sneakers (Wyon *et al.,* 2013a). These latter studies used time to stabilisation (TTS) protocols, which test dynamic stability. To date, there is a paucity of published articles on TTS tests and dancers. This test measures postural control, calculating stability indices in the anterior-posterior, medial-lateral and vertical directions. This field merits further research in order to investigate TTS as a relevant test for dancers' balance ability, as it measures functional balance which is relevant to the dynamic demands of dance (Flanagan, Ebben and Jensen, 2008).

Previous injury

Some studies compared balance to injury or joint instability. Clark and Redding (2012) found a significant link between previous lower limb injury and postural sway, concurring with previous studies and suggesting their balance tasks are a reliable method for identifying proprioceptive deficits from injuries. Lin *et al*. (2011) noted that injured dancers may have inferior postural stability to nondancers. The comparison of balance abilities between dancers and other groups has resulted in mixed findings, and as already noted, further replication of studies would increase the strength of evidence in this area.

Balance training and balance tests

Few alternative training protocols have been introduced to improve dancers' balance (Cloak *et al.,* 2010; Tekin *et al.,* 2018, Karim *et al.,* 2019). Therefore, this field remains relatively under-researched and merits further scientific attention due to the importance of balance ability in dance. Researchers need to include detailed methodologies of the interventions in RCTs so that replication is possible. As far as it is possible to ascertain, only one other study had designed a balance intervention (Hutt and Redding, 2014); however, given that it used volunteers of a younger age group, this study was not included in the review.

The validity and reliability of balance tests for dancers remains a largely un-researched area. Modifications to the Star Excursion Balance Test have been investigated by only two studies with the aim to examine its potential use as a dance-specific balance screening tool (Batson, 2010; Wilson and Batson, 2014). Balance research using dance-specific pirouettes has been undertaken (Golomer *et al.,* 2009a; Lott and Laws, 2012; Hopper *et al.,* 2014; Lin *et al.,* 2014b; Li *et al.,* 2014; Zaferiou, Wilcox and McNitt-Gray, 2016) but its validity as a balance tool is still under debate due to the variety of test conditions and small sample sizes. The variation in balance complexity may be related to the difference in results in the literature (Simmons 2005a), with a two-legged stance (Simmons, 2005a) being easier to maintain than a one-legged stance (Crotts *et al.,* 1996) or a balance position on a stabilometer (Golomer *et al.,* 1999a). Balance testing protocols need further scrutiny, as noted by Schmit and colleagues (2005) when evaluating the methods of a study, which produced conflicting results (Crotts *et al.,* 1996).

Although the force platform was the preferred testing apparatus, several studies used balance field tests, which did not rely on dedicated equipment, but produced conflicting findings. Studies using the SEBT as a measuring tool noted that some of the reach distance positions might be redundant (Cloak *et al.,* 2010; Ambegaonkar *et al.,* 2013; Batson, 2010), when modifications made to the SEBT resulted in non-significant disturbances to dancers' gaze (Batson, 2010). The study by Ambegaonkar and colleagues (2013) is the first to compare balance and non-dancers using the BESS, SEBT and BASS; the authors found that dancers had better balance than non-dancers in some but not all conditions. From the outcomes of the studies in this review, there does not appear to be one type of measuring tool or equipment which presents itself as providing the best evidence.

Strengths and Limitations

The present findings constitute a positive contribution to the existing body of knowledge as no such systematic review has been previously conducted. Another strength of this work is the detailed description of the search methodology. Medical Subject Heading (MeSH) terms were used in line with PRISMA statement recommendations (Liberati *et al.*, 2009). Articles have been rated according to GRADE guidelines (Guyatt *et al.*, 2011a) with recommendations for use for researchers new to GRADE assessments (Meader *et al.*, 2014). There were no language restrictions. It is reasonable to assume that the present results have been influenced by methodological limitations. The search terms were selected for the following reasons: they were the key words listed, the predominant terms used in titles in balance studies on dancers retrieved in earlier searches, and the terms matched closest to the focus of the systematic review. Nevertheless, the search terms used to identify relevant published material might not be entirely representative of the studied field, whilst the lack of detail in their methodology, small sample sizes, and the lack of limitations in a number of the selected studies, might have caused a degree of bias in the current analyses as previously indicated (Guyatt *et al.*, 2010; Balsham *et al.*, 2011). Age and maturation may be factors in vision and balance testing (Golomer, Dupui and Monod, 1997; Golomer *et al.*, 1999a), however, the inclusion criteria was restricted to adults only.

3.2.5 Conclusion

In conclusion, the limitations of the existing body of research on balance and dance performance have been exposed. Clear research questions, consideration of bias, strong inclusion and exclusion criteria and reporting in accordance to current scientific standards are recommended in the planning of future research studies. Further RCT research studies may increase the strength of available data and the presentation of evidence. In addition, further replication of balance studies and development of intervention studies might identify balance deficits and training needs for dancers. As no studies examined the relationship between balance ability and dance performance thus far, this area merits further consideration.

The literature on balance and dance performance revealed mixed findings. Reported effects on dancers' balance included task difficulty, and changes in vision conditions and somatosensory information. Balance strategies were employed by dancers in some conditions, however in other conditions, superior postural control was exhibited by dancers with less variability in the trunk and ankle. Based on this evidence, further research in balance training might suggest ways to maintain good postural control. In terms of assessing balance, no assessment tool demonstrated itself as providing best evidence. Given the importance of balance ability for dancers, further research studies meeting current scientific standards would be beneficial, and may enhance training programmes, optimal performance, and help to reduce the risk of injury.

4 Study 1: Associations between static and dynamic field balance tests in assessing postural stability of undergraduate female dancers

Parts of this chapter have been accepted for publication (Clarke *et al.*, in press)

4.1 Introduction

The systematic review of literature revealed that balance testing on dancers has utilised a wide variety of assessment tools but associations between these field tests have not been previously considered in dance research. Furthermore, as most of these tools were developed either for sport or elderly populations, the evidence of the relationships between tests or their functional relevance to dance is inconclusive.

Static and dynamic field balance tests are useful tools in assessing dancers' postural stability, as they can be set up and utilised in dance studios and laboratories; they are also quick and efficient to use. Field balance tests have been used to evaluate postural stability screening (Batson, 2010), rehabilitation work (Clark & Redding, 2012; Allen *et al.*, 2013) and to assess for investigations on specific sensory organisation of the visual, proprioceptive and vestibular senses (Batson, 2010; Rein *et al.*, 2017). However, this wide range of field assessment tools and test protocols employed for assessing dancers' balance have shown no evidence of replication power (Costa *et al.*, 2013) or analysis of potential associations between tests.

This limited knowledge in the field may impede the choice of appropriate tests to assess balance ability in training, screening, and research studies. Five field tests were selected for the study; they had all been used in previous published studies to assess the postural stability of adult dancers, either in full time dance training or working as professional dancers in theatrical dance genres. The tests varied in the nature of their test protocols, which may imply assessment of different aspects of postural stability. However, as the tests selected for this study were commonly used in screening, training programmes, and research tests on dancers, the analysis of possible associations between them was deemed to be important in order to examine their potential functional relevance for undergraduate dancers. Although assessments of dancers' balance ability have been based predominately on static balance tests (Costa *et al.,* 2013), assessment measures not utilising force plates, such as field tests, often use dynamic balance tests (Ambegoankar *et al.,* 2013). The majority of static balance tests perform one-legged stance positions (Schmitt, Kuni and Sabo, 2005; Golomer *et al.,* 2010; Bronner, 2012) which may not relate to the complex, dynamic dance movements in dance repertoire (Lin *et al.,* 2011).

Therefore, as both static and dynamic balance are essential skills in dance performance, the five tests included assessments of postural stability in static and dynamic balance tests. Three dynamic balance tests were selected: Star Excursion Balance Test (Gribble *et al.,* 2012), a pirouette test (Denardi *et al.,* 2008; Golomer *et al.,* 2009b; Lin *et al.,* 2011), the Airplane test (Richardson *et al.,* 2010), and two static balance tests were selected: modified Romberg (Rogers, 1980; Richardson *et al.,* 2010), the Biosway™ (Rein *et al.,* 2011). The aim of the study was to test the associations between five field balance tests employed in previous studies as revealed in Chapter 3. It was hypothesised that there would be no significant relationships between the five field balance tests.

4.2 Method

4.2.1 Study design

This observational study was designed to examine the association between five balance tests used to assess dancers' postural stability, and compared results from the three dynamic and two static balance tests.

4.2.2 Participants

Following approval by a University Ethics Committee, and *a priori* power analysis assuming an 80% power with an alpha level of 5%, a total of 83 female dance undergraduates (age: 20±1.5 years; height: 163.0±6.59 cm; mass: 60.9±10.76 kg; dance experience: 10±2.39yrs) were recruited for the study. All participants were studying on the same undergraduate dance programme and received equal hours of training in contemporary, ballet and jazz. Inclusion criteria specified that they attended dance classes for a minimum of 8 hours per week, were injury free, and that they were 18 years or older. Prior to testing, participants completed a consent form and a pre-activity health questionnaire and those with a known injury or illness were excluded.

4.2.3 Measures

The Star Excursion Balance Test (SEBT) has shown a strong interrater reliability of ICC=0.35-0.93 and intrarater reliability of ICC=0.78-0.96 (Hertel and Miller, 2000). The SEBT is marked out on a grid consisting of 8 lines marked on the floor, extending from a common point at 45˚ angle increments. The reaching directions were referenced according to the supporting leg as anterior (0˚), anteromedial (45˚), medial (90˚), posteromedial (135˚), posterior (180˚), posterolateral (225˚), lateral (270˚), and anterolateral (315˚). The test was performed on a single leg stance with the middle of the standing foot over the centre of the grid. The non-weight bearing leg extended along each designated line to maximal reach whilst maintaining the support foot on the floor and their upright posture facing the front (Gribble *et al.,* 2012) (Figure 4.1). The SEBT procedure was demonstrated by the researcher and participants performed practice trials to ensure accuracy in alignment and foot placement before the reaching distances were measured. The average of three trials was taken for each leg. The participants were instructed to bend their supporting leg as much as possible and reach in the eight directions, touching the furthest point with the most distal part of the foot.

At the point of touchdown of the reaching leg, a mark was made by the researcher. Participants were not allowed to slide the foot or to put weight on the reach foot. Termination of tests criteria were displacement of the supporting foot and if weight was put on the reach foot (Kinzey and Armstrong 1998). Leg reach distances were measured (cm) for each reach direction from the centre of the grid to the touchdown mark. This researcher's intratester reliability for the SEBT was tested with a reliability of ICC=0.99 (CI: .999, 1.00). The reach distances in each direction were normalised to % leg length (Gribble and Hertel, 2003; Ambegaonkar *et al.*, 2013). Participants had a short rest between different legs but the SEBT is not considered a fatiguing test for dancers.

Figure 4.1 Participant on SEBT: Performance of the Star Excursion Balance Test using the left leg as the limbstance in the medial direction

Pirouettes are a recognised dance-specific balance test with en dehors turns being most widely used (Denardi, Ferracioli and Rodrigues, 2008; Golomer, Gravenhorst and Toussaint, 2009; Lin *et al.*, 2014). Although, to date, no pirouette tests have been empirically validated (as noted in Chapter 3), pirouettes are recognised as having functional relevance when measuring dancer's postural stability (Lin *et al.,* 2011). Single en dehors pirouettes (Denardi *et al.,* 2008; Golomer *et al.,* 2009b; Lin *et al.,* 2011) were selected for this study replicating the predominant use of dehors pirouettes in published studies (as revealed in the systematic literature review in Chapter 3). In the pirouette test, participants were instructed to perform six single en dehors turns consecutively, starting from and returning to, a small open turned out position of the feet with one foot crossed in front of the other (4th position). Tests were conducted on both legs. The pirouettes were conducted on the ball of the foot (*demi pointe*), and during rotation, both legs were rotated outwards, with the non-weight bearing leg bent with a 90˚angle at the knee joint, and toes in contact and placed in front of the knee of the supporting leg *(retiré).* The arms were held in front of the body (1st position) during the rotation. The timing of the sequential turns replicated a commonly used waltz tempo (approximately 96BPM) in Intermediate level ballet classes, and with which the participants were familiar. Participants wore soft, thin-soled ballet shoes for the pirouette tests. Before testing began, a mark was taped to the floor to signal the start position of the supporting foot. At the start of the test, participants placed the ball (head of the metatarsals) of their front foot on the marker on the floor. At the end of the sixth turn, the final position of the ball of the front foot was marked and the displacement distance from the start mark to the finish mark was measured in centimetres (cm). Termination of tests criteria were the inaccurate placement of feet in the turn preparation position and the non-weight bearing foot touching the floor during a turn.

The Airplane test has been determined as a reliable indicator of a dancer's functional balance skill level (Richardson *et al.,* 2010; de Wolf *et al.,* 2018). The single-leg balance task was conducted in bare feet. The tests started with the non-weight bearing leg extended to the posterior direction creating a horizontal line with the torso which is flexed at 90˚. The arms were abducted to 90˚ in the start position (Richardson *et al.*, 2010) (Figure 4.2). The test consisted of five bends of the supporting leg with the arms adducted horizontally in order to touch the floor with the fingertips (Richardson *et al.*, 2010). As the support leg extended to return to the start position, the arms abducted horizontally again to 90˚. The number of times the fingertips touched the floor was recorded up to, and including, five (0-5) instances. The termination test criterion was displacement of the supporting foot, knee valgus, hip internal rotation, or pelvic drop (Richardson *et al.*, 2010).

Figure 4.2 Participant on Airplane test: Performance of the Airplane test (start position)

The Romberg test is a widely used neurology test (Rogers, 1980) with various modifications (Khasnis and Gokula, 2003; Richardson, Liederbach and Sandow, 2010). The Romberg selected for this study was modified to provide a potentially greater balance challenge for dancers, replicating an earlier study on dancers (Richardson, Liederbach and Sandow, 2010). The test comprised a single-leg balance in a parallel bare foot stance. It was conducted with the non-supporting leg slightly bent at retiré height and not touching the supporting leg. Arms were crossed across the chest and a blindfold was worn (Khasnis and Gokula, 2003; Richardson *et al.*, 2010). Romberg tests are commonly measured up to 30 seconds' duration (Richardson *et al.*, 2010), subsequently this protocol was followed with the additional data recording of sustained balances up to a minute, so 0-60 seconds, allowing for the participants' healthy profile and skill ability (Marulli *et al.*, 2017). Termination test criterion was the non-weight bearing foot touching the floor and pronation of the supporting foot.

The BioSway^{TM} (Biodex Medical Systems Inc, New York, USA) used for the purposes of this study has shown acceptable intratester reliability of ICC= 0.82-0.43 for stability index and ICC= 0.81-0.55 for foot placement, with the overall stability index scores showing the most reliable stability scores (0.82 for intratester and 0.70 for intertester) (Schmitz and Arnold, 1998). The Biosway Balance System tests used in this study assessed neuromuscular control by measuring a participant's ability to maintain unilateral postural stability on a static surface. The Postural Sway test used the Stability Index to quantify a participant's ability to maintain their centre of balance in unilateral stance. The tests were conducted with eyes open in single-leg stance and participants were asked to look ahead during the tests. Participants were barefoot and asked to step onto the platform and to place their arms in a neutral position. Foot position coordinates marked out on the platform were maintained for the supporting foot throughout all the trials. Participants performed three 20 second trials on each leg. Data quantified postural stability: overall stability, anterior/posterior and medial/lateral, and the overall stability data was recorded for further analysis. Data were excluded if the non-supporting foot was put down, or if the supporting foot moved from the marked coordinates.

4.2.4 Procedures

Prior to balance testing, anthropometric data were obtained from all volunteers, including leg length. The latter was measured with the participant lying supine, from the anterior superior iliac spine to the medial malleolus using an anthropometic tape measure (Kinzey and Armstrong, 1998, Gribble and Hertel, 2003). Following the initial assessments, all participants completed a 15-minute standardised warm up session. The same researcher conducted the tests and ensured accurate positioning, alignment and performance of all participants during testing. Participants took part in tests in a randomised order; the order of supporting leg was also randomised in each test.

4.2.5 Data Analyses

All variables were tested for normality using the Kolmogorov-Smirnov and Shapiro-Wilk test. Following the results of testing, Spearman's Rank Order Correlation (rho) was selected for correlational analysis of the data. The strength of the value of the correlation coefficient (rho) was determined by Cohen's (1988) guidelines and interpreted based on the following scale: 0.10 to 0.29 (small), 0.30-0.49 (medium), 0.50 to 1.0 (large).Statistical significance was set at $p<0.05$ using the SPSS 26 (IBM Corporation, Chicago, Ill).

4.3 Results

Test descriptive measures are presented in Table 4.1. Spearman's correlations for all test variables are presented in Table 4.2. The strongest correlations were shown for the following SEBT reach directions: SEBT 45˚ and SEBT 90˚ ($r = 0.809$, $p < 0.01$), SEBT 135˚ and SEBT 180˚ ($r = 0.808$, $p < 0.01$), SEBT 225˚ and SEBT 270˚ ($r = 0.787$, $p < 0.01$), SEBT 0˚ and SEBT 45˚ ($r = 0.776$, $p < 0.01$). Some further fairly strong to moderate correlations between SEBT variables can also be seen in Table 4.2. Otherwise the Romberg showed a weak correlation with SEBT 0˚ ($r = 0.240$, $p < 0.01$), the Pirouette test showed weak correlations with SEBT 0˚ ($r = 0.193$, $p < 0.05$), SEBT 45˚ ($r = 0.202$, $p < 0.05$), SEBT 180˚ ($r = -0.203$, $p < 0.05$), SEBT 225˚ ($r = -0.256$, $p < 0.01$) and SEBT 270˚ ($r = -0.236$, $p < 0.01$). The Biosway™ showed moderate correlations with SEBT 0˚ ($r = 0.307$, $p < 0.01$) and SEBT 45˚ ($r = 0.307$, $p < 0.01$) and weak correlations with SEBT 90˚ ($r = 0.208$, $p < 0.05$), SEBT 225˚ ($r = -0.247$, $p < 0.05$) and SEBT 270˚ ($r = -0.250$, $p < 0.05$). The Airplane test showed a weak correlation with the Romberg ($r = 0.295$, $p < 0.01$).

Table 4.1 *Mean and Standard Deviation of the measures of the field balance tests*

Variables	Mean ± SD
SEBT 0° (n=158)	65.53 ± 11.02
SEBT 45° (n=158)	69.31 ± 11.32
SEBT 90° (n=158)	77.10 ± 13.20
SEBT 135° (n=158)	84.86 ± 12.68
SEBT 180° (n=158)	88.39 ± 14.93
SEBT 225° (n=158)	84.07 ± 17.41
SEBT 270° (n=158)	73.14 ± 21.04
SEBT 315° (n=158)	69.12 ± 28.12
Romberg (n=158)	34.55 ± 16.90
Pirouette (n=148)	48.50 ± 31.34
Biosway (n=100)	0.78 ± 0.40
Airplane (n=114)	4.61 ± 0.93

Note: right and left legs tested so n=total number of leg tests. Units of measurement: SEBT reach directions were measured in centimetres (cm), Romberg in seconds (30s limit but recorded up to 60s); Pirouettes in cm, Biosway™ in Stability Index (sway) and Airplane in touches to floor (1-5).

Table 4.2 *Spearman's correlation analysis between field balance tests*

	SEBT 0°	SEBT 45°	SEBT 90°	SEBT 135°	SEBT 180°	SEBT 225°	SEBT 270°	SEBT 315°	Romberg	Pirouette	Biosway	Airplane
SEBT 0°	-	.776**	.600**	.447**	.370**	.205**	.080	.500**	.240**	.193*	.307**	.159
SEBT 45°	-	-	.809**	.569**	.408**	.167*	-.008	.318**	.148	.202*	.300**	.145
SEBT 90°	-	-	-	.728**	.509**	.269**	.030	.256**	.084	.065	.208*	.097
SEBT 135°	-	-	-	-	.808**	.591**	.366**	.506**	.050	-.115	.049	.023
SEBT 180°	-	-	-	-	-	.778**	.549**	.682**	.134	-.203*	-.079	.113
SEBT 225°	-	-	-	-	-	-	.787**	.695**	.065	-.256**	-.247*	.019
SEBT 270°	-	-	-	-	-	-	-	.620**	-.032	-.236**	-.250*	.056
SEBT 315°	-	-	-	-	-	-	-	-	.135	-.074	.030	.164
Romberg	-	-	-	-	-	-	-	-	-	.028	-.092	.295**
Pirouette	-	-	-	-	-	-	-	-	-	-	.100	.033
Biosway	-	-	-	-	-	-	-	-	-	-	-	-.047
Airplane	-	-	-	-	-	-	-	-	-	-	-	-

SEBT = Star Excursion Balance Test

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

4.4 Discussion

The aim of this study was to assess associations between static and dynamic balance tests used to measure postural stability in dancers. Although the results indicated strong relationships between some SEBT reach directions, other relationships between balance test variables were weak except for a moderate correlation between the Biosway^{TM} and SEBT 0˚ and the Biosway^{TM} and SEBT 45˚. The only correlation not including a SEBT reach direction was between the Airplane and Romberg although this was a weak relationship. In this study, the eight SEBT reach directions were assessed rather than a composite SEBT score or the Y test to see if any of the eight directions had an association with each other or with the other balance tests. Those SEBT directions demonstrating the strongest relationships with other directions were close in proximity on the SEBT grid although it is not possible to ascertain potential causes of these associations. However, it should be noted that dancers use these directional positions frequently in their training, for example, in movements such as *ronds de jambes*, and this may have elicited a training effect. Performance adaptations may also have occurred due to dancers' familiarisation with the SEBT directions in their dance practice. In reference to dancers' abilities in the SEBT reach directions, the few studies utilising the SEBT in studies on dance populations have reported mixed results. For example, a randomised controlled trial testing eight SEBT directions following a whole body vibration (WBV) intervention, noted an improvement in the anterior, anteriomedial, medial and anterior lateral directions (Cloak *et al.*, 2010), whilst dancers achieved higher scores than non-dancers in the medial and posteriomedial planes of movement (Ambegaonkar *et al.*, 2013). In a study by Armstrong *et al.* (2018), fatigue had no effect on SEBT performance possibly due to performance adaptations. Currently, there is inconclusive evidence in the literature on dancers' balance ability in the SEBT reach directions.

Whilst these five tests have been used previously in research studies on dancers' balance, it was acknowledged that each test has different protocols and conditions, resulting in some variations in assessment of postural stability, and this does not necessarily diminish the value of each task. A key example is the Romberg performed with eyes closed. Mixed findings have been reported on dancers' balance ability in vision conditions (Chapter 3) and it has been argued that whilst dance training increases the influence of proprioceptive skills over vision information, dancers' balance strategies rely on different senses in the multimodal processing depending on the specific balance task (Bläsing *et al.*, 2012). Although clinical assessments have identified classifications of balance and postural control strategies for those with balance problems (Horak *et al.*, 2009; Dewar *et al.*, 2017), to date, no such balance tool is available for assessing dancers. The five tests in this study demonstrate some resonance with the clinically based Balance Evaluation Systems Test (BESTest) (Horak *et al.*, 2009), most notably, the pirouette in their Anticipatory Postural Adjustments category and the Romberg in their Sensory Orientation category but it should be remembered that the BESTest was designed for a very different population.

In previous literature, the SEBT, Airplane, Biosway™, Romberg, and Pirouette tests have been identified as reliable or accepted balance tasks for the dance population (Denardi, Ferracioli and Rodrigues, 2008; Richardson, Liederbach and Sandow, 2010; Golomer, Gravenhorst and Toussaint, 2009b; Lin, Chen and Su, 2014b; de Wolf *et al.*, 2018). It is possible that in past research, assumptions have been made about the functionality of the tests for dancers even though there have been clear differences in test conditions and no replication of studies, for example, pirouette studies which have included a range of differing turn tasks (Denardi, Ferracioli and Rodrigues, 2008; Golomer, Gravenhorst & Toussaint, 2009b; Lin, Chen and Su, 2014b). Therefore, the predominately weak associations between these field tests revealed in this study may suggest that some balance measures are more relevant to some genres, such as pirouettes to ballet, and some may be inadequate for an accurate assessment of dancers' postural stability. However, this may not diminish the validity for some of the tests for different populations. The participants in this study were undergraduate dancers and injury free and it should be noted that there may be differences in what the tests evaluate for postural stability for alternative populations. For example, different results might be elicited in a symptomatic dance population or for professional dancers. .

When considering the relevance of balance tests employed in research on dancers, several factors need be considered. To date, screening, research studies, and rehabilitation work with dancers have employed a battery of field balance tests as indicated in Chapter 3 but these tests may have little or no predictive power. The lack of replicated studies in balance research on dancers (Chapter 3) has implications for the conclusions drawn from balance studies. Assumptions on the functionality and relevance of balance tests for dancers are likely to have been made over the years but reported results may need to be considered within the context of assessed study limitations in the literature (Guyatt *et al.,* 2011b; Meader *et al.,* 2014; Chapter 3).

Another factor to be considered when assessing balance tests is the task difficulty. Balance tests do not necessarily produce challenging enough demands for dancers (Stins *et al.,* 2009; Burzynska *et al.,* 2017; Costa de Mello *et al.,* 2017). Dancers' balance has been found to be more automatised than non-dancers (Stins *et al.,* 2009) with greater behavioural flexibility (Schmit, Regis and Riley 2005) and less cognitive involvement (Stins *et al.,* 2009). They use a wide range of balance strategies to maintain, achieve or restore equilibrium and have fast anticipatory reactions. Stins and colleagues (2009) note that attentional requirements for maintaining balance are skill dependent, and dancers have better balance control than nondancers (predominately in eyes open tasks); also dancers' increased use of somatosensory information is a key factor in their anticipatory responses (Simmons, 2005a;

Stins *et al.*, 2009). It has been suggested that dancers may reach a ceiling effect in postural automaticity particularly in eyes open tasks (Stins et al, 2009), due to their perceptual-motor skill resulting in a greater degree of automatic balance control which is resistant to disruptive interventions. Further balance study limitations can include levels of expertise (Stins *et al.,* 2009), for example, if the task is too simple, and not challenging enough for the level of expertise of the dancers being assessed (Lobo da Costa *et al.*, 2013) or alternatively, too demanding for participants (Lott and Laws, 2012). Notwithstanding these results indicating weak correlations between specified static and dynamic balance tests, further investigation in this area of research is merited.

Strengths and Limitations

To date, this is the first study to examine potential associations between specific balance tests employed to measure dancers' postural stability. The relatively large number of volunteers could also be treated as a study strength (Meader *et al.*, 2014). However, the present results may have been subject to certain methodological limitations. There is no agreed definition for the wider construct of postural control or stability for dancers (Dewar *et al.,* 2017). The postural control and movement complexity required for the SEBT and Airplane could be regarded as only moderately challenging for dancers. In addition, reach distances in the SEBT may have been subjected to participants' own exertion and interpretation of the given instructions. The Biosway™ may not have posed a sufficient challenge for the participants as it was a static position and resembled a basic element of dance technique. A limitation was that participants were undergraduate dance students and testing on professional dancers might have yielded different results, particularly in the pirouette tests. There were varying levels of expertise in the pirouette test and it is possible that some participants were holding the body in a rigid position due to a learned effect or misperception of the required technique (Lott and Laws, 2012).

4.5 Conclusion

The findings indicated significant associations between some SEBT reach directions and between some SEBT directions and the Romberg, Pirouette, and Biosway^{TM}, and between the Airplane and Romberg. Except for the associations between some SEBT directions, the strength of the associations between most tests was weak. Overall, these weak associations between tests may suggest that some balance measures have limitations in assessing accurately dancers' postural stability and may not challenge dancers who have demonstrated greater behavioural flexibility in balance tasks. Therefore, this study has pointed to the need for both further investigation of potential associations between balance assessment tools utilised to assess dancers' postural stability and dancers' performance, and the development of a dance-specific balance tool for a range of dance genres.

5 Study 2: Associations between field balance tests and dance performance

Parts of this chapter have been published: (Clarke *et al.*, 2019)

5.1 Introduction

Although balance is a key element of dance, it remains to be confirmed which balance components are associated with dance performance, and to date, the relationship between balance ability and dance performance has not been considered in the literature. Associations between balance ability and selected performance measures have been reported in sport (Hrysomallis, 2011). However, although the significance of elements such as muscular strength (Koutedakis, Stavropoulos and Metsios, 2005; Twitchett *et al.*, 2010), aerobic power (Twitchett *et al.*, 2011b; Wyon *et al.*, 2016), and overtraining (Koutedakis, 2000) have been studied in dancers, balance ability and its relation to theatrical dance performance remains unclear.

Studies have investigated dancers' balance ability in relation to expertise (Stins *et al.*, 2009), aesthetic competence (Angioi *et al.*, 2009), fitness (Strešková and Chren, 2009), dancers' balance ability compared to non-dancers (Perrin *et al.*, 2002; Rein *et al.*, 2011), the effects of balance training on the performance of balance tests (Watson *et al.*, 2017), and balance in relation to dance injury (Clark and Redding, 2012), but none have looked at theatrical dance performance thus far. For the purposes of the current study, dance is defined as theatrical dance, demonstrating a high level of skill, original form, and created for an audience (Martin, 1965; Paskevska, 2005).

The lack of replication of balance studies on dancers, and conflicting results may be linked to the considerable differences in testing apparatus (Chapter 3). Furthermore, although balance is often regarded as a key skill for dance performance (Paskevska, 2005), currently, there is no clear evidence for its support. In this thesis, dance performance is defined as highly skilled, focused embodiment of movement, demonstrating artistry and contextual understanding of the role. Whilst tests have assessed either dynamic or static balance in different genres, no studies have investigated the predictive association of balance ability on dance performance. Therefore, the aim of the study was to test the assumption that balance ability is associated with dance performance. It was hypothesised that there would be no significant relationship between balance and ballet, contemporary, and jazz technique competency.

5.2 Method

5.2.1 Study Design:

This cross-sectional study was designed to examine the association between balance ability and dance performance and compared results from five field balance tests to performance grades in three different dance genres (contemporary, ballet, and jazz). The dependent variables were the performance grades for contemporary, ballet, and jazz technique and repertoire assessments. The testing and grading protocols of the performance grades are well tested but not yet empirically validated. The independent variables were the balance tests.

5.2.2 Participants

Following approval by the university ethics committee from the University of Wolverhampton, and *a priori* power analysis assuming an 80% power with an alpha level of 5%, a total of 83 female university dancers (age: 20±1.5 years; height: 163.0±6.59 cm; mass: 60.9±10.76 kg; dance experience: 10±2.39 years) were recruited for the study. All participants were enrolled in an undergraduate dance programme and received equal hours of training in contemporary, jazz and ballet. Inclusion criteria specified that they were 18 years of age or older, that they were injury free, and attended dance classes for a minimum of 8 hours per week. Participants completed a pre-activity health questionnaire prior to testing and those with a known illness including heart complaint, neuromuscular, and neurological disease, or taking medication that influences balance ability were excluded. Participants were informed verbally and in writing about the procedures and they signed an informed consent before they were included in the study.

5.2.3 Measures

Balance tests

The data from the five field balance tests from Study 1 and described in 4.2.3, was used in this study.

Performance grades

Technique and repertoire grades were utilised for dance performance scores. As stated earlier in 5.2.1, the testing and grading protocols of the performance grades are well used but not yet empirically validated. Assessors and participants were blinded to the use of performance grades thus reducing performance bias (Meader *et al.,* 2014), and detection bias (Meader *et al.,* 2014). The department's procedures for marking dance performance and accuracy in moderating grades meet the UK Benchmarks for the Performing Arts in Higher Education Institutions (HEIs) and have been recognised as exemplary for over 15 years in External Examiners' Reports received by the university's Quality Department. External Examiners in UK HEIs are selected for their expertise in their subject and have to meet exacting criteria for selection. All practical assessments were assessed in live performance and filmed for further analysis if required. All participants performed the same number of repetitions of exercises in technique or repertoire sequences as required by the assessors.

Repertoire can be defined as the body of pieces which are regularly performed. Contemporary technique comprised of movements from the codified techniques of Martha Graham and Merce Cunningham, and jazz technique comprised of the codified styles of Matt

Mattox and lyrical jazz. Ballet repertoire was taken from two modern ballets by Maurice Bejart, contemporary repertoire was taken from works by Graham, Cunningham, Doris Humphrey and Twyla Tharp, jazz repertoire was taken from works by Bob Fosse and Michael Bennett. Assessment criteria for technique and repertoire grades were based on the following components: technical skills, musicality, spatial awareness, dynamic range, artistry and, for the repertoire, interpretation of the role. The criteria had been agreed by Department members and accepted by the External Examiner for the university dance programme.

For all the assessments, the grades were agreed by the independent assessors within one mark to be accepted as accurate and meeting benchmark criteria. Grade descriptors were adhered to in moderation meetings, and the grades given adhered to the university marking requirements. The university descriptions of the mark ranges were as follows: Retrievable Fail: 32-39%, Satisfactory (Pass): 40-49%, Good: 50-59%, Very Good: 60-69%, Excellent: 70-79%, Outstanding: 80-89%, Exceptional: 90-100%. The assessments were blind marked by two lecturers from the Dance Department, moderated by a third marker from the same Department, and accepted by the university exam board. The assessors and participants were blinded to the aims of the present study.

5.2.4 Procedures

All participants completed a 15-minute standardised warm up session prior to data collection. The warm up consisted of pulse raising activities, joint mobilisation exercises and dynamic stretches. The same examiner demonstrated the movements of each of the tests and conducted all the tests for all participants. Leg length was measured from the anterior superior iliac spine to the medial malleolus (Kinzey and Armstrong, 1998). The testing order of the balance tests was randomised; the order of the supporting limb was randomised in each test.

5.2.5 Data analyses

Standard regression analysis was conducted to detect which balance tests best predicted performance ability. The dependent variables were the performance grades for the ballet, contemporary and jazz technique and repertoire assessments. The independent variables were the balance tests (SEBT, Airplane, Pirouettes, Biosway^{TM} and Romberg). Statistical significance was set at $p<0.05$ using the SPSS 20 (IBM Corporation, Chicago, Ill).

5.3 Results

The mean and standard deviation data for the performance grades and balance tests scores showed variability for left and right leg SEBT data (Tables 5.1 and 5.2 respectively). Variability was shown also in the mean and SD data for Romberg, Airplane, Biosway^{TM}, and Pirouette with examples of higher SD for the Pirouette tests across all genres in technique and repertoire (Table 5.3).

Table 5.1 *Mean and SD of performance grades and SEBT balance test scores (left leg)*

Genre, and Performance descriptors	Descriptors (%)	SEBT Left leg reach distances (cm)							
		0˚	45˚	90˚	135˚	180˚	225˚	270˚	315˚
Ballet Technique									
Fail	38±0	62.1±27.15	60.5±16.82	61.7±12.30	75.55±21.99	85.7±35.77	76.75±28.21	79.5±42.28	75.9±41.71
Satisfactory	45.18±3.06	60.62±9.74	65.84±10.96	71.5±12.42	80.52±12.59	81.75±10.60	76.16±11.82	63.6±17.40	53.02±13.45
Good	54.61±2.71	65.26±11.67	71.14±13.44	78.03±13.95	84.5±12.41	87.49±12.73	82.75±15.92	72.54±19.72	67.21±15.02
Very good	63.52±2.69	67.77±12.67	68.86±10.21	79.85±12.62	90.26±12.83	91.28±16.82	88.67±17.04	76.63±21.12	66.42±12.72
Excellent	71.62±1.40	68.27±9.91	75.01±13.63	88.96±17.47	89.3±13.39	94.81±15.31	86.41±15.43	71.27±14.35	65.47±7.17
Ballet Repertoire									
Satisfactory	45.36±2.90	53.34±8.56	58±11.16	66.66±10.60	73.8±11.39	74.43±11.79	71.04±13.32	62.4±13.55	50.28±11.19
Good	55.04±2.96	67.15±9.56	72.92±10.96	79.63±14.82	85.39±11.71	89.30±11.80	83.67±13.98	71.36±18.26	66.31±15.02
Very good	63.40±2.43	67.15±11.61	70.75±12.01	80.31±12.80	90.61±12.44	91.76±14.52	86.45±17.03	76.41±21.65	69.07±14.47
Excellent	72.2±1.92	65.22±8.47	73.4±12.14	85.64±20.42	88.86±13.24	98.08±19.46	94.76±15.33	77.48±24.15	63.36±7.22
Contemporary Technique									
Fail	35.6±3.28	57.26±14.73	58.94±10.24	65.48±7.98	76.62±12.54	81.7±19.70	76.82±17.80	70.8±24.30	62.1±26.19
Satisfactory	45.33±3.82	62.08±9.90	66.46±9.99	73.26±13.33	83.76±13.29	87.76±8.60	82.26±15.20	69.4±26.22	61.06±21.06
Good	54.62±2.82	64.05±11.30	71.07±12.81	76.67±14.28	81.34±12.74	83.80±12.73	78.79±14.54	68.63±19.00	61.71±14.29
Very good	63.52±2.48	69.66±12.19	70.95±12.30	82.04±13.95	91±11.09	93.58±16.25	87.73±17.01	74.76±18.43	68.20±12.87
Excellent	71.66±1.63	64.9±9.32	73.68±11.67	86.6±16.55	93.78±13.58	93.75±10.95	93.3±13.43	78.45±23.85	68.4±8.86
Outstanding	80±0	59±0	60±0	67±0	69±0	76±0	78±0	84±0	59±0
Contemporary Repertoire									
Fail	38±0	50.9±0	49.2±0	62±0	71.5±0	71.5±0	61.3±0	50.7±0	41.7±0
Satisfactory	44.83±2.63	62.68±16.67	65.7±12.99	72.28±15.35	82.32±15.71	86.6±19.58	77.76±16.87	67.06±29.13	60.96±27.39
Good	56.04±2.90	64.6±11.41	69.19±13.39	77.14±14.63	83.23±11.84	86.9±13.21	82.50±15.41	70.09±16.17	64.33±13.28
Very good	64.12±2.80	68.06±12.84	71.51±11.85	81.63±13.67	90.68±13.09	91.03±15.38	86.39±16.59	75.39±21.19	67.58±14.54
Excellent	72±1.68	64.73±8.75	70.73±10.78	78.11±15.60	83.90±13.16	88.83±15.54	84.90±16.15	74.41±19.59	63.74±11.86
Jazz Technique									
Satisfactory	45.66±2.96	60.23±11.78	62.87±10.47	66.64±14.16	76.71±15.32	82.35±15.01	75.81±14.05	67±21.45	58.75±19.67
Good	54.55±2.87	65.46±13.09	72.78±14.86	80.44±14.55	83.30±10.91	85.18±12.84	75.23±9.78	64.32±13.92	61.03±12.52
Very good	63.31±2.45	68.29±12.56	70.19±10.26	80.2±11.18	87.93±10.48	90.42±12.66	90.08±14.44	78.05±16.95	69.76±13.70
Excellent	72.38±1.98	65.17±8.00	70.06±11.75	81.45±16.56	93.36±14.39	95.21±18.84	91.59±19.76	78.89±25.99	66.63±14.21
Jazz Repertoire									
Satisfactory	45.37±2.82	53.85±9.09	58.33±11.49	64±16.03	72.86±13.25	76.98±10.98	71.06±11.39	63.6±13.06	51.6±9.67
Good	54.65±2.72	68.17±13.92	71.68±13.84	79.10±14.88	83.00±12.82	87.24±15.58	78.34±13.41	66.00±18.29	63.17±15.36
Very good	64.04±2.83	64.85±10.00	70.91±10.81	81.27±14.53	89.62±11.52	90.13±11.79	89.31±14.43	77.11±17.69	67.71±14.32
Excellent	72.83±2.28	67.77±9.24	69.75±10.18	78.77±9.23	90.88±12.02	93.95±18.15	89.79±19.71	80.10±24.91	69.00±14.18

Descriptor percentages: Satisfactory = 40-49%, Good = 50-59%, Very Good = 60-69%, Excellent = 70-79%, Outstanding = 80- 89% (*none awarded above 89%)

Table 5.2 *Mean and SD of performance grades and SEBT balance test scores (right leg)*

Genre, and Performance descriptors	Descriptors (%)	SEBT Right leg reach distances (cm)							
		0˚	45˚	90˚	135˚	180˚	225˚	270˚	315˚
Ballet Technique									
Fail	38±0	58.1±20.08	63.6±24.04	64.45±13.93	83.25±23.54	85.7±35.49	88.7±39.45	78.05±31.18	69.05±26.65
Satisfactory	45.18±3.06	63.64±8.63	66.97±10.38	75.26±12.13	81.99±13.29	81.64±8.32	74.86±12.24	62.57±18.27	59.19±8.89
Good	54.61±2.71	65.52±10.46	69.50±10.61	76.87±13.89	84.34±12.62	88.36±13.44	83.04±17.45	75.87±19.72	67.94±12.39
Very good	63.52±2.69	67.62±10.79	69.79±10.47	76.95±10.55	85.09±9.40	88.75±15.11	85.77±19.47	73.00±24.79	71.77±20.28
Excellent	71.62±1.40	68.02±6.21	71.7±7.78	81.06±10.08	83.45±12.19	91.28±13.79	82.23±14.20	59.05±19.78	69.27±14.48
Ballet Repertoire									
Satisfactory	45.36±2.90	57.7±8.34	62.47±11.54	69.35±11.45	75.38±10.83	76.11±8.49	72.26±10.09	64.85±11.59	54.56±7.74
Good	55.04±2.96	66.53±8.76	70.72±8.71	77.98±10.42	84.32±9.87	88.30±12.37	82.47±18.51	72.98±20.98	69.35±14.08
Very good	63.40±2.43	68.82±11.05	70.34±11.32	77.38±13.29	86.36±12.52	89.65±14.33	85.71±17.56	77.02±21.71	71.86±16.97
Excellent	72.2±1.92	64.32±5.88	69.6±9.80	83.04±13.10	88.96±11.89	98.26±16.26	90.26±18.43	42.34±20.15	67.64±13.58
Contemporary Technique									
Fail	35.6±3.28	59.2±10.12	63.94±12.44	67.92±10.99	79.54±12.38	82.9±18.47	78.46±22.22	68.68±18.49	61±16.13
Satisfactory	45.33±3.82	64.06±10.55	65.42±12.72	78.88±12.40	86.86±13.96	90.7±15.53	85.62±26.09	72.2±36.22	71.2±16.81
Good	54.62±2.82	65.93±9.36	69.16±10.00	75.29±13.95	83.12±14.10	84.65±13.31	78.52±15.34	71.77±17.85	63.19±10.10
Very good	63.52±2.48	67.30±11.42	70.11±10.61	78.38±10.59	83.96±9.11	88.42±11.75	84.04±15.60	70.49±21.12	70.50±15.40
Excellent	71.66±1.63	68.51±5.04	75.33±6.70	81±12.81	90.78±10.90	98.71±18.11	92.93±23.03	76.03±29.27	78.78±25.72
Outstanding	80±0	59±0	61±0	78±0	75±0	80±0	83±0	36±0	60±0
Contemporary Repertoire									
Fail	38±0	60.2±0	63.5±0	68.9±0	75.5±0	74±0	66.3±0	54.3±0	49.3±0
Satisfactory	44.83±2.63	62.76±13.22	66.64±13.72	72.54±15.45	82.84±13.20	85.5±17.81	77.2±23.24	64.22±24.53	64.34±14.77
Good	56.04±2.90	66.88±10.14	69.60±10.90	76.73±11.26	84.25±10.54	85.96±9.82	80.97±14.84	72.40±16.83	68.54±12.87
Very good	64.12±2.80	66.60±11.13	70.21±10.91	77.48±13.07	84.21±12.27	88.90±15.33	84.83±16.89	76.76±20.70	69.64±17.98
Excellent	72±1.68	64.8±7.09	68.51±8.40	77.79±12.04	84.55±13.54	90.23±16.26	84.7±21.50	61.52±27.82	66.52±15.53
Jazz Technique									
Satisfactory	45.66±2.96	62±9.06	68.07±9.99	72.96±12.12	82.07±14.04	83.65±14.49	73.33±20.21	64.24±19.95	61.7±11.59
Good	54.55±2.87	66.07±11.42	68.01±11.98	74.57±12.92	80.51±10.62	82.86±9.60	76.72±9.71	67.38±16.21	63.07±9.79
Very good	63.31±2.45	67.35±10.57	70.65±10.05	79.31±11.55	85.70±10.29	88.35±11.57	87.41±16.17	79.16±17.25	71.13±15.72
Excellent	72.38±1.98	66.32±7.63	69.76±9.70	78.66±12.20	87.95±13.24	96.82±18.50	90.43±21.66	67.21±32.68	74.31±21.06
Jazz Repertoire									
Satisfactory	45.37±2.82	56.88±10.10	62.21±15.39	68.2±12.89	79.25±12.24	79.33±10.80	69.06±16.66	64.95±13.37	56.01±6.88
Good	54.65±2.72	66.60±10.11	69.99±9.35	75.72±11.91	81.47±11.67	84.70±12.22	78.38±14.81	67.17±19.54	66.4±12.97
Very good	64.04±2.83	66.47±9.30	68.9±9.49	77.48±11.51	85.59±9.90	89.17±12.97	86.5±15.05	78.17±18.82	69.24±15.29
Excellent	72.83±2.28	68.12±10.02	72.19±10.92	81.75±12.42	88.44±14.10	94.85±17.33	90.25±22.48	67.10±31.23	74.22±20.30

Descriptor percentages: Satisfactory = 40-49%, Good = 50-59%, Very Good = 60-69%, Excellent = 70-79%, Outstanding = 80- 89% (*none awarded above 89%)

Table 5.3 *Mean and SD of performance grades and Romberg, Airplane, Biosway and Pirouette balance test scores*

Genre, and Performance descriptors	Descriptors (%)	Romberg (secs)		Airplane (touches out of 5)		Biosway (stability index)		Pirouette (displacement cm)	
		Left	Right	Left	Right	Left	Right	Left	Right
Ballet Technique									
Fail	38±0	27.66±4.93	23.66±5.50	3.66±2.30	3.33±2.08	0.69±0.31	0.68±0.07	15±1.41	23.5±16.26
Satisfactory	45.18±3.06	26.6±18.48	22.7±15.49	4.55±1.01	4.66±1	0.79±0.34	0.66±0.17	43.1±21.57	63.85±35.84
Good	54.61±2.71	26.27±16.27	24.86±12.23	4.54±0.97	4.54±1.06	0.78±0.36	0.78±0.47	41.22±24.45	59.13±40.59
Very good	63.52±2.69	28±14.09	32.93±13.23	4.70±0.68	4.88±0.33	0.79±0.41	0.72±0.30	47.26±26.38	60.41±39.63
Excellent	71.62±1.40	32.4±4.27	36.5±11.48	5±0	4.71±0.48	0.89±0.61	0.79±0.67	58.12±45.22	44.86±35.84
Ballet Repertoire									
Satisfactory	45.36±2.90	19.4±11.46	17.3±10.20	4.11±1.53	4.11±1.53	0.77±0.30	0.72±0.16	37±16.18	54.81±24.08
Good	55.04±2.96	27.28±16.06	25.59±12.62	4.63±0.68	4.68±0.94	0.82±0.39	0.72±0.46	43±26.01	64.02±44.77
Very good	63.40±2.43	30.55±15.69	33±12.59	4.65±0.93	4.84±0.46	0.84±0.43	0.83±0.45	50.06±32.56	58.74±37.96
Excellent	72.2±1.92	34.25±7.18	35.75±13.07	5±0	4.6±0.54	0.52±0.20	0.46±0.10	36.6±31.95	23.98±18.62
Contemporary Technique									
Fail	35.6±3.28	23.2±11.12	21.4±11.05	3.25±2.06	4±1.41	0.52±0.07	0.61±0.03	30±19.03	41.2±27.41
Satisfactory	45.33±3.82	28.66±12.84	23.83±12.10	5±0	4.2±1.78	0.73±0.32	0.62±0.15	35.8±24.80	66.6±36.86
Good	54.62±2.82	26.66±17.99	24.45±14.07	4.72±0.55	4.59±1.05	0.80±0.38	0.76±0.47	40.83±22.56	64.22±42.95
Very good	63.52±2.48	28.80±14.95	33.90±13.25	4.59±1.00	4.86±0.46	0.91±0.43	0.86±0.44	51.72±30.88	57.47±37.45
Excellent	71.66±1.63	27.2±7.94	26.2±6.18	4.66±0.81	4.66±0.51	0.57±0.23	0.45±0.15	40.83±36.30	41.48±41.27
Outstanding	80±0	60±0	60±0	5±0	4±0	0.38±0	0.44±0	86±0	49±0
Contemporary Repertoire									
Fail	38±0	30±0	30±0	-	-	-	-	23±0	21±0
Satisfactory	44.83±2.63	26.16±14.57	21.83±10.72	3.83±1.83	3.66±1.75	0.65±0.23	0.65±0.06	40.8±27.50	54.6±31.18
Good	56.04±2.90	28.05±13.82	22.89±12.77	4.63±0.68	4.68±0.94	0.94±0.35	0.84±0.46	49±24.84	63.52±41.29
Very good	64.12±2.80	25.26±16.98	30.95±13.87	4.66±0.96	4.85±0.47	0.81±0.45	0.81±0.51	42.11±27.26	57.79±37.03
Excellent	72±1.68	31.2±14.68	32.3±12.32	4.76±0.59	4.76±0.43	0.68±0.35	0.59±0.25	46.23±36.08	51.03±41.32
Jazz Technique									
Satisfactory	45.66±2.96	25.08±12.79	24.41±9.55	4.36±1.43	4.27±1.42	0.68±0.23	0.68±0.12	31.9±21.16	58.3±36.21
Good	54.55±2.87	26.87±16.68	25±17.13	4.70±0.58	4.47±1.17	1.00±0.39	0.88±0.57	48.47±31.67	66.26±46.52
Very good	63.31±2.45	24.42±13.53	27.66±8.18	4.47±1.07	4.78±0.53	0.74±0.37	0.75±0.39	52.28±24.81	58.52±26.61
Excellent	72.38±1.98	39.25±12.36	37.5±14.27	4.84±0.55	4.84±0.37	0.65±0.41	0.6±0.30	38.46±30.50	42.37±42.08
Jazz Repertoire									
Satisfactory	45.37±2.82	19.37±11.74	17.87±11.64	3.66±1.75	3.66±1.75	0.80±0.35	0.78±0.17	37.5±18.58	50.5±21.60
Good	54.65±2.72	30.47±15.45	27.66±13.55	4.8±0.52	4.7±0.92	0.92±0.38	0.88±0.50	40.38±28.77	63.09±42.84
Very good	64.04±2.83	24.38±16.16	29.45±13.08	4.52±1.03	4.80±0.51	0.72±0.39	0.68±0.42	52.77±25.29	57.47±33.27
Excellent	72.83±2.28	34.55±9.15	32±11.71	4.83±0.57	4.83±0.38	0.72±0.40	0.60±0.24	42.33±34.77	49.57±45.69

Descriptor percentages: Satisfactory = 40-49%, Good = 50-59%, Very Good = 60-69%, Excellent = 70-79%, Outstanding = 80- 89% (*none awarded above 89%)

The SEBT 90˚ and the Romberg test were best associated with all three genres of technique (Table 5.4). Significant regression was found: ballet ($F_{(3,124)}$ = 7.894, p=.001), with an R^2 of .163, and contemporary ($F_{(3,124)}$ = 6.407, p=.001), with an R^2 of .134. The SEBT 90˚, SEBT 315˚, and SEBT 225˚, and the Romberg test were best associated with jazz technique ($F_{(4,123)}$ = 10.666, p=.001), with an R^2 of .258.

Table 5.4 *Variables that best predicted technique and repertoire performance grades*

Genre	Technique class	Repertoire
Ballet	r=0.4, p=0.001 SEE±2.49. SEBT 90 beta=0.295, p=0.001; Romberg beta=0.251, p=0.003	r=0.508, p=0.001 SEE±1.99. SEBT 90 beta=0.201, p=0.015; SEBT 225 beta=0.401, p=0.002; Romberg beta=0.270, p=0.001
Contemporary	r=0.366, p=0.001 SEE±2.67. SEBT 90 beta=0.367, p=0.013; Romberg beta=0.222, p=0.01	r=0.269, p=0.015 SEE±2.29. SEBT 225 beta=0.217, p=0.02
Jazz	r=0.507, p=0.001 SEE±2.28. SEBT 90 beta=0.161, p=0.046; SEBT 315 beta=0.166, p=0.045; SEBT 225 beta=0.425, p=0.001; Romberg beta=0.201, p=0.012	r=4.14, p=0.001 SEE±2.29. SEBT 225 beta=0.279, p=0.001; Romberg beta=0.219, p=0.009

Star Excursion Balance Test (SEBT):SEBT 90 = medial (90˚), SEBT 225 = posterolateral (225˚), SEBT 315 = anterolateral (315˚). Note: the reaching directions are referenced according to the supporting leg.

In repertoire, SEBT 225˚ was best associated with all three dance genres (Table 5.4). SEBT 90˚, and SEBT 225˚, and the Romberg test were best associated with ballet ($F_{(4,123)}$ = 10.691, p=.001), with an R^2 of .258. SEBT 225˚ was best associated with contemporary ($F_{(2,111)}$ = 4.327, p=.015), with an R^2 of .072, and SEBT 225˚ and the Romberg test were best associated with jazz ($F_{(3,124)}$ = 8.526, p=.001), with an R^2 of .171.

5.4 Discussion

The aim of this study was to examine the association between balance ability and dance performance, with particular reference to the genres of ballet, contemporary and jazz. The results suggest that some balance tests indicated predictive ability on dance performance (technique and repertoire) in all three genres (Table 5.4). However, the prediction strength of these balance assessment tools was relatively low. Within this framework, the Romberg was the predominant predictor of successful performance, indicating an association with all of the dependant variables, except contemporary repertoire; it is noteworthy that this was the only test performed with eyes closed. Nevertheless, it is not possible to ascertain the causes of the association between the Romberg and dance performance from these results. Evidence on dancers' balance abilities when visual information is removed remains inconclusive. The dependence of dancers on visual information for regulation of postural control has been previously identified (Perrin *et al.,* 2002; Pérez *et al.,* 2014), where a decrease in balance performance in eyes closed conditions has been found possibly because dance classes and performances do not demand balance ability with eyes closed (Gerbino, Griffin and Zurakowski 2007). In these eyes closed conditions a shift from visual to somatosensory information has been identified (Golomer and Dupui, 2000; Simmons, 2005a) particularly in dynamic balance tasks (Golomer and Dupui, 2000). In static, balance tasks with eyes open/closed, dancers relied more on visual information than somatosensation, displaying better balance in eyes open conditions (Hugel *et al.,* 1999; Perrin *et al.,* 2002), and worse balance than controls and judoists when visual information was removed (Perrin *et al.,* 2002). In contrast, dancers demonstrated better balance abilities than non-dancers in eyes closed timed static balances (Crotts *et al.,* 1996). Furthermore, pre-professional dancers showed improvement in some timed balance tests, measured in time and distance, following an eyes closed balance intervention programme (Hutt and Redding, 2014). A study on brain structure and function revealed that dancers' balance performance was not related to their dance training compared to non-dancers (Burzynska *et al*, 2017), and that dancers may have reached a ceiling for their balance performance. In contrast, when visual information is removed, dancers may face more challenging tasks to maintain postural stability (Hugel *et al.*, 1999; Perrin *et al.*, 2002; Simmons, 2005a).

The other most common predictors of successful performance were two reach distances in the SEBT: the SEBT 90˚ and SEBT 225˚ (Table 5.4). The regression between the ballet, contemporary and jazz technique scores and SEBT 90˚ results may indicate a learning effect from their training in those genres as they use extended lines to the side (90˚). This concurs with published data whereby dancers may have had more practice in certain reach directions in the SEBT due to their dance participation (Ambegaonkar *et al.*, 2013). The correlation found between SEBT 225˚ and the repertoire scores in ballet, contemporary and jazz may reflect a balance strategy using the torso to counterbalance (Batson, 2010). Although the posterolateral reach distance (225˚) is less prevalent in codified technique training, the repertoire pieces in the three dance genres were demanding in both spatial components and aesthetic competence.

A number of balance tests (Airplane, pirouette, Biosway™, SEBT reach directions (0˚, 45˚, 135˚, 180˚, 270˚) did not demonstrate any predictive power for dance performance. Research has shown that balance tests do not necessarily produce demands which are challenging enough for dancers (Stins *et al.*, 2009; Burzynska *et al.*, 2017), and to date, there is limited evidence for the relevance of these balance tests in dancers due to an absence of replicated studies (Chapter 3) and study limitations (Meader *et al.*, 2014; Chapter 3). Nevertheless, pirouettes are regarded as a more challenging balance task for dancers (Lott and Laws, 2012; Lin *et al.*, 2014) requiring postural adaptations for successful rotations (Lott and Laws, 2012). In the future, pirouette test protocols tested for validity and reliability with subsequent replication may reveal different results, albeit with limitations already discussed. The highest regression scores were shown between SEBT 90˚, SEBT 225˚ and Romberg and the ballet repertoire scores, suggesting that these balance tests should be considered in future research. However, it must be noted that whilst these tests were predictors of ballet repertoire performance (25.8%), and jazz technique (25.8%), these values are relatively low, and they demonstrated weaker associations with contemporary technique and repertoire. Thus, their predictive ability for different dance genres remains unclear. Whilst our results indicate that certain balance tests have low to moderate predictive ability on dance technique and repertoire, further investigation into more functionally relevant, dance-specific measureswith closer replication to dance performance is recommended.

Strengths and limitations

The present findings constitute a positive contribution to the existing body of knowledge as no such study on associations between balance ability and dance performance has been previously conducted. However, it is reasonable to assume that the present results may have been influenced by some methodological limitations. The grading of performance marks assessed optimal dance performance is an in-house measure, which has not been empirically validated to date, but this protocol could be an opportunity for further research. Whilst pirouettes have been recognised as a functional, dance-specific balance test in a number of studies, this assessment tool has not been empirically validated but may merit further investigation. Participants demonstrated varied experience in the technical demands of the dance-specific pirouette test, and a few participants exhibited occasional weakness in alignment when executing a series of single pirouettes during testing, in part, due to their undergraduate level of skill. The examination of performance scores has been limited to those in theatrical dance. The variability in the performance of the balance tests may indicate variability in the balance versus performance scores.

5.5 Conclusion

Within its limitations, the present study indicates low to moderate associations between balance, dance technique, and repertoire performances, thus challenging the traditionally held perception of the importance of balance ability for optimal dance performance in an in-house measure. The regression between the SEBT 90˚, SEBT 225˚, and Romberg and ballet repertoire revealed the strongest association between balance tests and dance performance. Although the findings indicate that both static and dynamic balance ability may be of benefit to dance performance, the predictive ability was moderately low and the SEBT reach directions (90˚, 225˚) appear to be random. Measures which are regarded as more functionally relevant, such as time to stabilisation, may be more appropriate for dancers. Further investigation of balance tests which replicate functional movement in dance, is suggested in order to advance the predictive ability of balance tests on dance performance.

6 Study 3: Bilateral differences on dancers' dynamic postural stability during jump landing

Parts of this chapter have been published: (Clarke *et al.,* 2020)

6.1 Introduction

Functional relevance of balance tests has been suggested as key to obtaining information on balance ability in movements that replicate the sport and dance techniques (Wikstrom *et al.,* 2005; Mertz and Docherty, 2012). The previous studies in chapters 4 and 5 have demonstrated that current balance tests may not be fit for purpose in assessing dancers. Traditional dance training aims to train dancers' legs equally, but the recognised practice of predominately starting and repeating exercises on one side more than the other has led to suggestions that technique classes may cause lateral bias (Farrar-Baker and Wilmerding, 2006; Kimmerle, 2010; Mertz and Docherty, 2012). Such an imbalance could lead to a greater risk of injury, and a probable decrease in aesthetic quality, however, despite this potential risk, little is known about the effects of bilateral differences on dancers' postural stability during jump landings, a key dynamic action in dance. Available data are both scarce and contradictory. A study examining lateral differences in postural stability in a jump protocol noticed that self-reported leg differences did not correlate with balance ability in ballet jump-landings (Mertz and Docherty, 2012). Whereas another study indicated bilateral differences in *grand jetés* on the non-dominant leg in take off and landing (Wyon *et al.,* 2013b).

When dancers perform different types of jumps, they are expected to execute them efficiently (Cunningham *et al.,* 1998; Laws, 1995), and maintain the aesthetic standards of a particular movement. Therefore, ground reaction forces (GRFs) generated by the whole body, especially during jump-landings, are an important consideration in investigating landing technique and postural control. These GRFs have been previously studied in dancers performing jump landings by comparing full foot to pointe (Chockley, 2008), flat shoes to pointe shoes (Walter, Docherty and Schrader 2011), and postural stability to GRF (Mertz and Docherty, 2012). Shoes with thicker soles have decreased GRFs in jump landings for dancers (Walter, Docherty and Schrader, 2011) and a greater force was generated when landing on the full foot compared to *en pointe* (Chockley, 2008) which has a smaller base of support. Differences in jump height caused differences in GRF values due to the ankle's limited range of motion in that position (Chockley, 2008). Further studies have examined landing biomechanics in dancers in relation to gender (Orishimo *et al.,* 2009), floor incline (Pappas *et al.,* 2012), and barefoot vs. shod conditions (Fong Yan *et al.,* 2014). However, although these studies have assessed jump landings, they have not examined dancers' postural stability or lateral bias in that task.

The Dynamic Postural Stability Index (DPSI) (Wikstrom *et al.,* 2005; Wikstrom *et al.,* 2010) was selected for this study, because it is a functional measure of dynamic postural stability, which discerns how well balance is maintained when the participant progresses from a dynamic to static state, indicating sway through all planes. The DPSI is a composite of the GRF in all planes and is sensitive to force changes in each direction. In particular, it is an informative measure of neuromuscular control because it is calculated in single-leg stabilisation movements, and poor landing strategies are more likely to occur in single-leg landings, which are more challenging than double-leg landings for dancers (Niu *et al.,* 2013).

Therefore, the aim of this study was to examine the effects of possible bilateral differences on dynamic postural stability during single-leg landing using a time to stabilisation protocol. It was hypothesised that bilateral differences would have no effect on postural stability in jump landings.

6.2 Method

6.2.1 Study design:

This observational study was designed to examine the effects of bilateral differences on postural stability in a time to stabilisation test (Wikstrom *et al.,* 2005; Wikstrom *et al.,* 2010).

6.2.2 Participants

The total of 32 female dance undergraduate students (age: 19±1.19 yrs; height: 164.8±6.68 cm; mass: 62.6±13.59 kg; dance experience: 9±2.46 years) were recruited for the study, following *a priori* power analysis assuming an 80% power with an alpha level of 5%. All participants were enrolled in an undergraduate dance programme and received equal hours of training in contemporary, jazz and ballet. Inclusion criteria specified that they were 18 years of age or older, that they were injury free, had the ability to jump barefoot without discomfort, and attended dance classes for a minimum of 8 hours per week. Participants completed a pre-activity health questionnaire prior to testing and those with a known illness including heart complaint, neuromuscular, and neurological disease, or taking medication that influences balance ability were excluded. The study was approved by the University of Wolverhampton, and all participants signed an informed consent form prior to data collection.

6.2.3 Measures

Wikstrom's Dynamic Postural Stability Index (DPSI) which has demonstrated excellent reliability (ICC= 0.91-.98) for DPSI index (Wikstrom *et al.,* 2005) was utilised in this study. This is an objective measure of postural control which is used with a functional jump protocol. Stability indices (SIs) are calculated in the three directions: anterior-posterior (APSI), medial-lateral (MLSI), vertical (VSI), and the DPSI which a composite of the three planes (Wikstrom *et al.,* 2005). These indices assess the standard deviations of fluctuations around a zero point. These are then divided by the number of data points in a trial with greater variability indicated by higher scores (Wikstrom *et al.,* 2010). The DPSI demonstrates a sensitivity to change in three directions but, whilst taking a global measure, does not lose the individual directional measurements. This allows researchers to note any directional deficits and the effects on the global measure (Wikstrom *et al.,* 2010).

6.2.4 Procedures

GRFs data were collected on a force plate (Bertec, Columbus, OH, USA) considering the following directional indices: anterior-posterior stability index (APSI), medial-lateral stability index (MLSI), vertical stability index (VSI) and the dynamic postural stability index (DPSI), as previously described (Wikstrom *et al.*, 2010). All participants completed a standardised 15-minute cardiovascular warm up including jogging, skipping and gallops prior to data collection. Preceding the trials, the participants' maximum vertical jump was tested. They were tasked to perform to three countermovement vertical jumps on a jump mat (Probotics Inc, Huntsville, AL) and the highest score was recorded for further analyses.

Each trial began with participants standing 70cm from the centre of the force plate (Ross, Guskiewicz and Yu, 2005; Wikstrom *et al.,* 2010). Trials consisted of a bare foot jump-landing task from two feet to one foot over a bar onto the force platform stabilising as quickly as possible (Ross, Guskiewicz and Yu, 2005; Wikstrom *et al.,* 2010). The bar was set at 50% of each participant's maximum jump height (Ross, Guskiewicz and Yu, 2005). Participants were asked to jump over the bar landing on the predetermined landing foot, in a foot position parallel to the sides of the force plate. If participants hopped or touched the floor on landing with their non-stance leg, then the trial was discarded and repeated.

The order of performance was randomly assigned using the sealed envelope method. Three trials were performed on each leg. Participants were instructed to hold the landing position for the duration of 3 seconds for the researchers to collect the required data (Wikstrom *et al.*, 2010). Two researchers were present during trials which were observed and filmed to ensure that jumps were accurately performed, in particular, taking off from two feet. Perceived leg dominance was determined by two dance-specific questions: the preferred supporting leg for a jump landing on one foot and gesture leg in retiré position (Lin, Su and Wu, 2005; Kimmerle, 2010).

A custom Microsoft Excel (2010) script file was used to process the ground reaction force data for calculating DPSI (Figure 4). The DPSI is a composite of the anterior-posterior, medial-lateral, and vertical ground reaction forces. The DPSI was calculated using the first 3 seconds of the ground reaction forces immediately following initial contact identified the instant the vertical ground reaction force exceeded 5% body weight. This method of calculating DPSI has demonstrated good test–retest reliability (Lin *et al.*, 2011).

Variable	Equation
MLSI	$\left(\sqrt{\frac{\sum(0-GRFx)^2}{number\ of\ data\ points}}\right) \div BW$
APSI	$\left(\sqrt{\frac{\sum(0-GRFy)^2}{number\ of\ data\ points}}\right) \div BW$
VSI	$\left(\sqrt{\frac{\sum(0-GRFz)^2}{number\ of\ data\ points}}\right) \div BW$
DPSI	$\left(\sqrt{\frac{\sum(0-GRFx)^2+\sum(0-GRFy)^2+\sum(0-GRFz)^2}{number\ of\ data\ points}}\right) \div BW$

BW, body weight; ∑, Sum; GRFx, medio-lateral ground reaction force; GRFy, anterior-posterior ground reaction force; GRFz, vertical ground reaction force; MLSI, medio-lateral stability index; APSI, anterior-posterior stability index; VSI, vertical stability index; DPSI, composite score.

Equation 6.1 Calculation for DPSI

6.2.5 Data analyses

As previous research has reported independent contributions of legs in one-legged balance tasks (van Dieën, van Leeuwen and Faber, 2015), the independent t-test was used to analyse the data obtained from each participant's jump trials on both the right and left leg, using the SPSS (version 20) software. 95% confidence intervals (CI) and Cohen's d effect size measure (r^2) were also calculated. The level of significance was set at $p<0.05$.

6.3 Results

The results showed no significant differences between the right and left leg, with poor effect size. The independent t-test results were: MLSI: t= -.04, df= 190, p= .940 (CI= -.04,.04, r^2= 0); APSI: t= .65, df= 190, p= .519 (CI= -.06,-.12, r^2=.09); VSI: t= 1.85, df= 190, p= .066 (CI= -.02,.68, r^2= .27); DPSI: t= 1.88, df= 190, p= .061 (CI= -.02, .70, r^2= .27).

Table 6.1 shows the results presented as mean (±standard deviation) for both limbs. Further analysis of the differences between left and right legs in the DPSI scores showed that 46.15% of 32 participants demonstrated better postural stability on their left leg.

Table 6.1 *Mean and SD for force directions and composite score*

	MLSI	APSI	VSI	DPSI
Left (n=96)	0.29 ±0.14	1.03 ±0.3	3.42 ±1.49	3.60 ±1.48
Right (n=96)	0.29 ±0.13	1.00 ±0.33	3.09 ±0.91	3.26 ±0.96

MLSI, medial-lateral stability index; APSI, anterior-posterior stability index; VSI, vertical stability index; DPSI, composite score

The data distribution is shown in violin plots overlaid with box plots (Figures 6.1-6.4) for greater transparency. For each index, boxplots indicate the median and quartiles and the violin plots show the distribution of data and its probability density. In the violin plots, the width of the area represents the proportion of data located there.

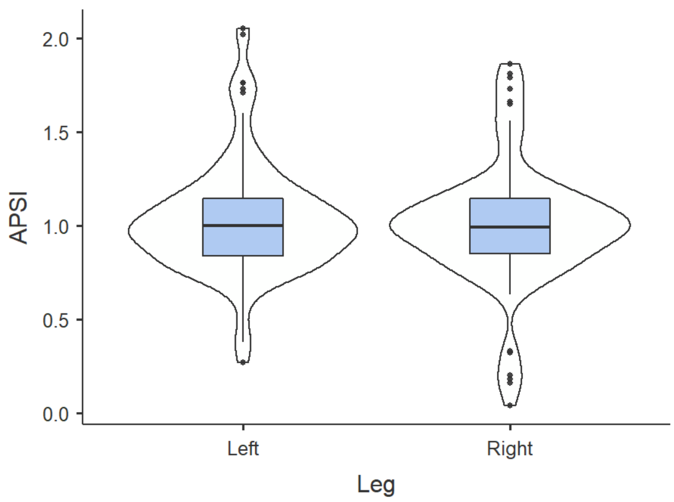

Figure 6.1 Data distribution for anterior-posterior stability index (APSI)

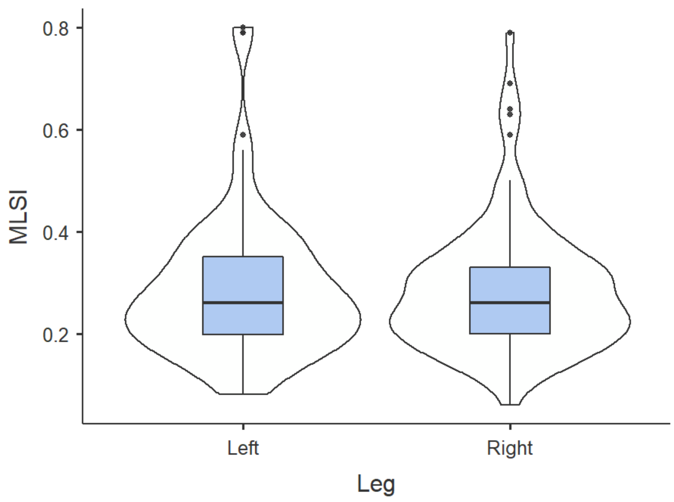

Figure 6.2 Data distribution for medial-lateral stability index (MLSI)

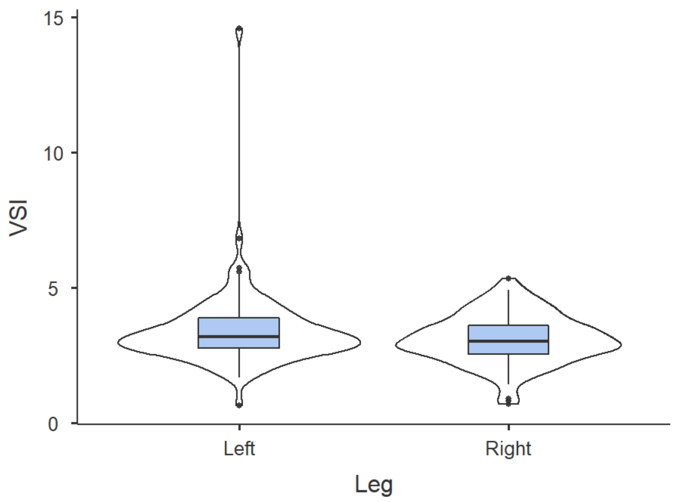

Figure 6.3 Data distribution for vertical stability index (VSI)

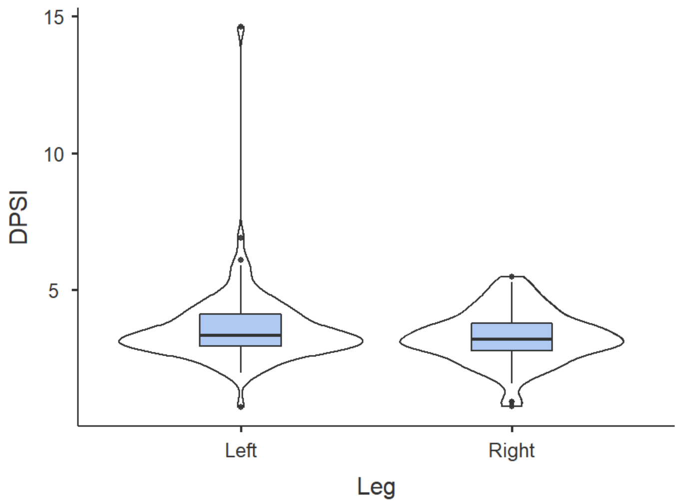

Figure 6.4 Data distribution for dynamic postural stability index (DPSI)

6.4 Discussion

The aim of this study was to examine the effects of bilateral differences on dancers' dynamic postural stability during jump landing. After statistical analysis, no significant difference was found in postural stability between legs in jump-landing. This concurs with existing information on bilateral differences and postural stability (Wikstrom *et al.*, 2006; Guillou, Dupui and Golomer, 2007; Niu *et al.*, 2013; Lin *et al.*, 2014a). The results also concur with the only study to date, which has examined the effects of leg differences on postural stability in dance-specific jump landings, where no differences in the dancers' postural control in the anterior-posterior or medial-lateral directions were found (Mertz and Docherty, 2012). In line with other sportspeople (Muehlbauer *et al.,* 2019), dancers often identify a "stronger" or "preferred leg". Recent research has shown that in complex dance tasks, the preferred leg may be dependent on the given task (Kimmerle, 2010), and leg preference does not correlate with balance ability while landing from ballet jumps (Mertz and Docherty, 2012).

Although it is often assumed that dancers use their legs equally, it has been suggested that technical training may contribute to functional differences between the legs (Farrar-Baker and Wilmerding, 2006; Kimmerle, 2010). In terms of teaching and learning bias, it has been suggested that dancers are likely to have different responses to training (Roberts, Eisenhower and Gamboa, 2004; Kimmerle, 2010), and perceived competence on one leg or another needs further consideration. The lack of bilateral differences in jump landing demonstrated in several studies does not mean that there is a lack of proficiency in the dancers' landing strategies. A further consideration is the task difficulty. To date, studies have included balance tasks demonstrating a range of task difficulty (Chapter 3), and it has been suggested that balance tests do not necessarily produce demands which are challenging enough for dancers (Stins *et al.,* 2009; Burzynska *et al.,* 2017). However, the possible effects of increased neurophysiological demands on functional differences or perceived competence on one leg or another is not known.

Variables and laterality

Although greater stability values were demonstrated on the left leg in two indices (VSI and DPSI) this did not relate to a preferred (or dominant) leg and poor effect sizes were evident. Due to the limited research on both lateral preference and bilateral differences in dancers, it is difficult to draw firm conclusions. In studies on nondancers, it has been noted that forward jump landings produce increased VSI scores (Wikstrom *et al.,* 2008), and it is possible that TTS measures may be influenced by jump directions (Liu and Heise, 2013). However, it is not possible to ascertain if the jump directions were associated with the participants' experience of jumps in their normal physical activity. In further studies on laterality and dancers, non-dominant sides have shown poorer reactions to dance movements compared to the dominant side, in *relevés* (Lin, Su and Wu, 2005), and in *grande jetés* (Wyon *et al*., 2013b). The protocols to determine leg preference varied in the aforementioned studies, including a dance-specific question (Lin, Su and Wu, 2005; Kimmerle, 2010) but, important to note, these were based on range of motion rather than balance (Lin, Su and Wu, 2005), and on general leg preference tests (Wyon *et al.*, 2013b).

Functional relevance

As noted earlier, postural stability in dynamic movements such as jump landing phases, can be assessed by time to stabilisation tests (Flanagan, Ebben and Jensen, 2008). This type of test assesses the dancer's ability to transfer from a dynamic movement to a static stance and replicates dynamic dance movements more closely than static tests (Wikstrom *et al.*, 2005). To date, research examining balance and dance has used a range of measurement tools (Golomer and Dupui, 2000; Batson, 2010; Bruyneel *et al.*, 2010; Cloak *et al.*, 2010; Ambegaonkar *et al.*, 2013; Krityakiarana and Jongkamonwiwat, 2016). However, to the researcher's knowledge, only three studies on dancers have examined a dynamic movement to a static state using TTS protocols (Pappas *et al.*, 2011; Wyon *et al.*, 2013a; Miller *et al.*, 2018). This force-plate-measure is defined as the time required to stabilise quickly to a static state over the participant's base of support after a jump-landing task (Colby *et al.*, 1999). TTS is considered as a more functionally relevant measure than static-based assessments for athletic populations (Colby *et al.*, 1999; Reimann, Caggiano and Lephart, 1999; Wikstrom, Powers and Tillman, 2004) and dynamic measures have been developed to more closely replicate athletic performance, including reducing the time given to stablise (Wikstrom *et al.*, 2010). Research has shown that individuals with functionally unstable ankles take longer to stabilise during single-leg landings (Ross, Guskiewicz and Yu, 2005), as is the case with athletes who underwent anterior cruciate ligament reconstruction (Webster and Gribble, 2010). The limited literature on laterality differences in sports studies using TTS protocols has shown that there were no dynamic postural stability limb differences in double-leg (Niu *et al.*, 2013) or single-leg (van Dieën, van Leeuwen and Faber, 2015) landings, and this concurs with existing data on dancers (Mertz and Docherty, 2012) and the findings in this study.

Strengths and Limitations

The present findings constitute a positive contribution to the existing body of knowledge on laterality differences on dancers' dynamic postural stability. Another strength of this work is the inclusion of figures showing data distribution that adheres to recent guidelines for greater transparency of data in scientific research (Weissgerber *et al.*, 2016). It is reasonable to assume that the present results have been influenced by methodological limitations. The choice of methodology affects the results, and in this case, for example, using a multivariate analysis of variance would have reduced the likelihood of errors, and given more detailed analysis of the smaller effects on the dependent variables and possible connections between the dependent variables. The jumps used in this study were relatively simple and commonly adopted in class, but more complex jumps or induced effects such as a fatigue intervention might produce different results for bilaterality and postural stability. Although the parameters used for vertical height and horizontal distance were those previously outlined by Wikstrom and colleagues (2005), these parameters have not been consistent across all TTS studies (Gribble, Mitterholzer and Myers, 2012). However, the horizontal distance of 70cm has been used universally for all participants and this offers a degree of standardisation (Webster and Gribble, 2010). The same applies for the vertical height which was normalised to the individual participant (50% of the maximum jump height) (Gribble, Mitterholzer and Myers, 2012).

6.5 Conclusion

In conclusion, the current data revealed no bilateral differences in dynamic postural stability following jump landings and concurred with other findings on postural stability and bilateral differences. The results of this study do not support the notion that dance training may cause lateral bias with its associated risk of injury, although lateral bias may be present elsewhere. In addition, the dancers' self-perceived leg dominance did not correlate with their ability to balance in single-leg landings or to absorb GRFs often associated with injury. Therefore, even when unequal training exists, it may not have detrimental effects on the dancer's postural stability in key actions such as jump landings. The paucity of relevant research on the effects of bilaterality on postural stability in dance has led to limitations of evidence and further investigation is required to review other factors affecting performance and potential bilateral strategies in jump landings. Although this study's measures and procedures are viewed as functionally relevant in balance research, it is argued that the jump protocol utilised was not challenging enough for those with dance expertise, therefore further factors which can affect postural stability need to be manipulated.

It is proposed that potential bilateral differences in postural stability in dancers may be challenged more effectively by repeating the time to stabilisation test with a factor affecting performance. One such factor is fatigue which can decrease performance in balance tasks and increase the risk of injury. Whilst functionally relevant measures may replicate dance performance more closely than those developed for sport or rehabilitation purposes, the effects of fatigue have yet to be examined in time to stabilisation protocols on dancers.

7 Study 4: Effects of fatigue on bilateral differences on dancers' dynamic postural stability during landing

7.1 Introduction

Fatigue is a complex phenomenon as both psychological and physiological factors may be involved (Belza, 1994). It can be classified in different ways; "central" fatigue defines a subjective sensation of tiredness and exhaustion, whereas "peripheral" fatigue refers to a particular exhaustion of the muscles after exertion (Belza, 1994). As aforementioned, a sensation of fatigue is interpreted subjectively and, in the context of fatigue during exercise, can affect effort and motivation. Physiologically, fatigue may be defined as the decline in the force or power a muscle can produce (Enoka and Dachateau, 2008), and includes a perceived effort necessary to exert the required power or force output and a subsequent inability to do so (Davis and Bailey, 1997). Fatigue can affect performance by decreasing muscle coordination, neuromuscular control (Kellis and Kouvelioti, 2009) and joint integrity (Wojtys, Wylie and Huston, 1996) in different activities including dance (Wyon and Koutedakis, 2013c). This decrease in neuromuscular control can affect movement patterns and reduce balance stability. An impaired ability to maintain postural stability has been shown to reduce the aesthetic quality of movement and present a higher risk of injury in dancers (Wild, Grealish and Hopper, 2017).

Inadequate muscular strength levels, overtraining and overuse have been linked frequently to an association between fatigue and dance injuries (Koutedakis *et al.*, 2009; Liederbach, Schanfein and Kremenic, 2013; Murgia, 2013) with clear evidence of a predominance of lower extremity injuries (Liederbach, Schanfein and Kremenic, 2013). Jump landings have been linked to a high incidence of lower limb injuries in athletes (McNitt-Gray, 1991) and this has further implications for dancers, given the frequency of high loads on the knee joint in training and performance (Simpson and Kanter, 1997). Repetitive jumps in both ballet and contemporary may result in fatigue due to the demanding requirements of maintaining muscular control, coordination and aesthetic competency. Furthermore, controlled jumping and landing are key skills in dance performance and given the repetitive demands of dance and associations between fatigue and injury, it is important to examine how fatigue may affect postural stability which is linked to mastery of movement and the reduction of the risk of injury.

To the researcher's knowledge, previous research on the effects of fatigue on dancers' balance ability is limited to three studies. Coutts *et al.*, (2006) found that an incremental dance-specific fatigue protocol did not affect dancers' postural stability in an arabesque. Hopper and colleagues (2014) found that professional ballet dancers' static balance control was not affected by a ballet-specific fatigue test (30 seconds of *temps levés*) in contrast to the pre-professional and recreational dancers. Similarly, in a study by Armstrong and colleagues (2018), undergraduate dancers' dynamic balance control was not affected by the Dance Aerobic Fitness Test (DAFT) (Wyon *et al.*, 2003), a dance-specific field test. Different reasons were given for this resistance to fatigue. It was suggested that dancers may have had a disassociated attentional style relating to perception of exertion and potential balance strategies in low intensity fatigue (Coutts *et al.*, 2006). Hopper *et al.* (2014) suggested that the increased training loads for professional dancers may have resulted in the dancers' resistance to fatigue, and that the professional dancers may have developed adaptive strategies whilst undertaking the standing balance measures. Furthermore, professional dancers' interpretation of fatigue and its effects on motivation and effort are likely to be different to those with less experience and still in training. Kinematic strategies were also suggested by Armstrong *et al.* (2018) and they further argued that the dancers may have enhanced balance skills and a high level of proficiency in the balance measure (the SEBT), a sport-related field test. However, their findings indicated that the DAFT was sufficiently physiologically fatiguing for the dancers.

The influence of fatigue on time to stabilisation performance has not been considered for dancers. As fatigue has been shown to affect performance including implications for jump landings, the Dynamic Postural Stability Index (DPSI) (Wikstrom *et al.,* 2005; Wikstrom *et al.,* 2010), was selected for this study. To standardise the dance exercise component for this study, the DAFT (Wyon *et al.,* 2003) was selected. Specifically, this test is designed to fatigue the aerobic and anaerobic systems and has ecological validity for dancers.

The aim of this study was to investigate the effects of dance-specific fatigue on bilateral leg differences on postural stability in time to stabilisation performance. It was hypothesised that there would be no significant effect of fatigue on bilateral differences on postural stability.

7.2 Method

7.2.1 Study design:

This experimental study examined the effects of a fatigue intervention on postural stability in the time to stabilisation protocol used in the previous chapter (Wikstrom *et al.,* 2005; Wikstrom *et al.,* 2010).

7.2.2 Participants

Nine female dance undergraduates (age: 19±0.72yrs; height: 168.1±6.93cm; mass: 58.9±9.70kg) completed the study. All participants were enrolled in an undergraduate dance programme and received equal hours of training in contemporary, jazz and ballet. Inclusion criteria specified that they were: 18 years of age or older, injury free, able to jump barefoot without discomfort, and attended dance classes for a minimum of 8 hours per week. Participants completed a pre-activity health questionnaire prior to testing and those with a known illness including heart complaint, neuromuscular, and neurological disease, or taking medication that influences balance ability were excluded. The study was approved by the University of Wolverhampton ethics committee and *a priori* power analysis assuming an 80% power with an alpha level of 5%, was conducted for sample size. Participants were informed verbally and in writing about the procedures and they signed an informed consent before they were included in the study.

7.2.3 Measures

Using the same methodology in Chapter 6, Wikstrom's Dynamic Postural Stability Index (DPSI) (Wikstrom *et al.,* 2005) was used in this experimental study to measure time to stabilisation during the jump landings. Stability indices (SIs) were calculated in the three directions: anterior-posterior (APSI), medial-lateral (MLSI), vertical (VSI), and the DPSI which a composite of the three planes (Wikstrom *et al.*, 2005). The revised calculation by Wikstrom and colleagues (2010) were used in this study.

For the fatigue intervention, the Dance Aerobic Fitness Test (DAFT) (Wyon *et al.,* 2003) was selected. The DAFT is a reliable and valid field measure of a dancer's ability to cope with the physiological demands of class and performance (Wyon *et al.,* 2003) and has been demonstrated as producing a fatigue effect (Wyon *et al.*, 2003; Armstrong *et al.*, 2018). The loading in the DAFT has ecological validity and is commonly used by undergraduate dancers in training and screening.

7.2.4 Procedures

Time to stabilisation (DPSI)

Prior to data collection, all participants completed a standardised 15-minute cardiovascular warm up including jogging, skipping and gallops, and the participants' maximum vertical jump was tested. Replicating the previous study's procedures (Chapter 6), participants carried out three trials on each leg pre- and post the fatigue intervention.

Fatigue protocol

A reminder of the DAFT stages was given to all participants before the start of the testing session as participants were familiar already with the DAFT protocols. The DAFT consists of 5 x 4-minute stages of a 16-beat dance sequence (stages 1-2), increasing to 24 beats in stages 3-5. As the stages progress, the movement content intensifies in tempo, length of sequence, size of movement and additional movements. The researcher supervised the test.

7.2.5 Data analyses

A two factor mixed design ANOVA was conducted to compare the effects of fatigue on bilateral differences on postural stability. The within-subject factor was "fatigue" and between-subject factor was "leg" and the dependent variables were the directional indices (MLSI, APSI, VSI, and DPSI). Data analysis was conducted using the IBM SPSS (version 26) software. The level of significance was set at $p<0.05$.

7.3 Results

Results showed no significant interaction between fatigue and leg, for any dependent variables: MLSI: Wilks' Lambda = .99, $F(1,52) = .42$, $p = .52$, partial eta squared = .01; APSI: Wilks' Lambda = .98, $F(1,52) = .80$, $p = .37$, partial eta squared = .01; VSI: Wilks' Lambda = .99, $F(1,52) = .16$, $p = .69$, partial eta squared = .003; DPSI: Wilks' Lambda = .99, $F(1,52) = .14$, $p = .71$, partial eta squared = .003. There were no significant main effects for fatigue: MLSI: Wilks' Lambda = .96, $F(1,52) = 2.11$, $p = .15$, partial eta squared = .04; APSI: Wilks' Lambda = .97, $F(1,52) = 1.51$, $p = .22$, partial eta squared = .03; VSI: Wilks' Lambda = .95, $F(1,52) = 2.80$, $p = .10$, partial eta squared = .05; DPSI: Wilks' Lambda = .94, $F(1,52) = 3.00$, $p = .09$, partial eta squared = .05. Mean values with standard deviations (SD) pre- and post-fatigue are summarised in Table 7.1. The main effects between legs were not significant: MLSI: $F(1,52) = 2.51$, $p = .12$, partial eta squared = .05; APSI: $F(1,52) = .05$, $p = .81$, partial eta squared = .001; VSI: $F(1,52) = .07$, $p = .79$, partial eta squared = .001; DPSI: $F(1,52) = .04$, $p = .84$, partial eta squared = .001.

Table 7.1 *Mean and SD for force directions and composite score pre- and post-fatigue*

	Leg	MLSI	APSI	VSI	DPSI
Pre-fatigue	Left (n=27	0.31±0.13	0.93±o.23	3.60±1.90	3.76±1.86
	Right (n=27)	0.40±0.21	0.96±0.15	3.63±2.11	3.80±2.07
Post-fatigue	Left (n=27)	0.37±0.19	0.92±0.15	3.22±1.44	3.36±1.42
	Right (n=27)	0.42±0.20	0.91±0.16	3.01±0.65	3.19±0.63

MLSI, medial-lateral stability index; APSI, anterior-posterior stability index; VSI, vertical stability index; DPSI, composite score

7.4 Discussion

The aim of this study was to investigate the effects of dance-specific fatigue on dynamic postural stability in time to stabilisation performance and to establish whether these effects elicited bilateral leg differences in a jump landing. The results supported the null hypothesis that there would be no significant effect of fatigue on bilateral differences on postural stability. Neither leg differences nor fatigue had an effect on postural stability in the time to stabilisation tasks. Furthermore, the interaction between these factors showed no effect on the dancers' postural stability and there were no significant differences between pre- and post-fatigue scores. Although research has provided some evidence of a relationship between fatigue and diminished dance performance and increased risk of injury (Murgia, 2013; Liederbach, Schanfein and Kremenic, 2013), there is still a paucity of knowledge the effects of fatigue on balance (Liederbach, Schanfein and Kremenic, 2013). This is a pertinent point because balance is essential to mastery of technique (Liederbach, 2008) and may reduce injury risk (Hertel, Buckley and Denegar, 2001).

Laterality and postural stability

This study's findings concur with the previous study in Chapter 6, which found no dynamic postural stability limb differences in jump landings, and concurs with other research findings on dancers (Mertz and Docherty, 2012) and athletes (van Dieën, van Leeuwen and Faber, 2015) in jump landings. Although there has been an assumption that dance training may lead to lateral bias (Kimmerle, 2010), there remains inconclusive evidence for bilateral differences in this population.

Fatigue and postural stability

The resistance to fatigue could be for several reasons. The time to stabilisation jump protocol is similar to jumps executed in ballet and contemporary and was performed without the traditional use of turn out in ballet or arm gestures. Thus, the dancers may not only have had good proficiency in this movement task but may have found the test jump less challenging.

Secondly, in this study, observational live and film analysis of the jump landings showed a range of strategies employed by the dancers to maintain postural stability in the jump landing. Dancers are trained to perform take-off and landing of jumps in a controlled manner, maintaining an aesthetic quality at all times. This often requires the employment of balance strategies to maintain the required performance, both aesthetically (Wild, Grealish and Hopper, 2017) and in stabilisation (Batson, 2010; Wyon *et al.*, 2013b) and these strategies have been further reported in fatigue-effect studies. A creative approach to problem solving, such as achieving maximum SEBT reach distances even if movement quality was reduced, was suggested by Armstrong and co-workers (2018), and development of adaptive strategies in fatiguing motor training of professional dancers was noted by Hopper *et al.* (2014). It has been hypothesised that even if professional dancers are fatigued, they may be able to use performance strategies to compensate for reduced muscle efficiency and to maintain postural stability (Hopper *et al.*, 2014), however the authors note that muscular efficiency and fatigue need to be qualitatively measured before drawing conclusions. The deterioration of movement quality and alignment in the upper trunk and arms observed in some post-test jump landings could not be measured in the DPSI and this reinforces the argument for a dance-specific scoring system measuring both postural stability and postural control.

The fatigue intervention was deemed to be appropriate for the test and participants were asked to perform the DAFT until volitional failure to ensure the appropriate fatigue effect. Dancers' self-measured HR data was similar to findings in a similar study on undergraduate dancers (Armstrong *et al.*, 2018) which argued the DAFT had provided suitable physiological demands and elicited fatigue effects. Limitations of other fatigue measures have been noted in sport (Twist and Highton, 2013), therefore the DAFT was assessed to be the most appropriate for inducing fatigue.

Strengths and Limitations

To the best of our knowledge, this is the first study to examine the effects of fatigue using a dance-specific reliable test on dynamic movements; an important factor as the test more closely replicated dance movements. There are several limitations to this study. There was a poor attrition rate due to injuries (unrelated to the study). It is acknowledged that the final sample size of nine participants is relatively small with limited statistical power and effect. To overcome some of the problems related to small sample size, a two factor mixed design was conducted for this study. The DAFT loading has ecological validity and was deemed an appropriate fatigue intervention for the undergraduate participants, however, the inclusion of further physiological measures such as lactate or heart rate using HR monitors may have presented further valuable data. The subjective nature of the sensation and interpretation of fatigue is another consideration and a replication of this test on professional dancers may have yielded different results. The balance measure may not have been challenging enough for those with balance expertise, even with a change in conditions. Although this study examined an acute fatigue effect, further investigation into overuse risk injury might be considered in future studies (Murgia, 2013; Liederbach, Schanfein and Kremenic, 2013) due to the potential contribution of impaired movement patterns. Some deterioration of movement quality and alignment in the upper trunk and arms was observed in post-test jump landings, however this could not be measured in the DPSI. Whilst, these balance strategies may have had some effect on the indices data, it is not known to what extent the strategies, such as counter movement gestures, affect the data. Dancers have relied on an increased proprioceptive input when balance conditions are challenged (Golomer and Dupui, 2000), and further investigation into disrupting practised balance strategies in dance training and testing may identify changes in these strategies.

7.5 Conclusion

This study demonstrated that a fatigue condition had no significant effect on dancers' postural stability or bilateral differences in a time to stabilisation protocol. No previous studies have investigated the effects of fatigue on time to stabilisation performance of dancers. The findings concur with some other research studies on both fatigue and postural stability and laterality and postural stability. From the resistance to fatigue shown in this study, it may be suggested that dancers are not influenced by fatigue in time to stabilisation performance. Furthermore, balance strategies and adaptations are likely to have been adopted to achieve the desired outcome. However, these strategies could not be measured by the DPSI and there is a need for a dance-specific tool which measures both postural stability and control variability. Varied movement patterns in these adaptations may cause injury or impairment of performance and an investigation into different approaches to balance training may reveal responses to these strategies.

8 Study 5: Development of a balance scoring test: The Accumulation Balance Score

8.1 Introduction

Currently, there are no balance scoring systems designed for application in dance. There have been modifications to sports tests for dancers such as the mSEBT (Batson, 2010), and dance-specific tests on pirouettes (Lin *et al.,* 2014b), but to date, the published tests on pirouettes produce no reliable measurements. As previously noted, dancers are expert in emplying complex balance strategies and there may a ceiling effect in current testing tools (Burzynska *et al.*, 2017). Therefore this study aimed to develop a dance-specific tool which captured data on postural stability and control so that more information could be available for the analysis of dancers' complex balance strategies. The advantage of developing an original dance-specific scoring system is based on its application for assessing balance in novel or existing dance sequences; no equipment is required and it can be applied to dynamic sequences including travelling movements/balance tasks. Consideration was given also to its design to facilitate application in both live assessments and recorded footage in any dance genre. A series of pilot studies revealed the importance of gathering data on postural control in body segments as well postural stability. This was deemed necessary so that data that are more comprehensive would be available for analysing dancers' balance strategies. In addition, the reliability of the Accumulation Balance Score needed to be established and the validity of the test needed to be assessed. Therefore, the aim of the study was to develop a novel balance scoring test for multiple types of testing and to assess interrater and intrarater reliability and validity of the test. It was hypothesised that there would be no significant difference in test-retest scores for the novel balance test.

8.2 Methods

8.2.1 Participants

The participants shown in the filmed footage for the reliability analysis were those from the study using time to stabilisation protocols in Chapter 7 (7.2.2). Three university dance lecturers with at least fifteen years' experience of assessing dancers were recruited as raters for the interrater analyses. They had all had professional dance training, postgraduate teaching qualifications, and had experience in teaching studio-based movement in dancers' health studies. Two further dance instructors were recruited for intrarater analyses. These raters taught in a pre-professional dance institution with similar backgrounds and qualifications to the university lecturers. All raters were experienced in assessing movement on film.

8.2.2 Measures

The DPSI time to stabilisation pre-recorded footage was selected for this reliability analysis footage due to its excellent ICC rating (DPSI ICC=.91-.98). The DPSI measures are described in Chapter 6 (6.2.2). Prior to the development of the Accumulation Balance Score (ABS), observational analyses on postural control responses and stability (time) in jump landings was collected in two previous studio-based pilot studies, in an earlier lab-based study using a force plate, and in adage positions and balance tasks in dance sequences. Filmed evidence of the movement material was observed and analysed, and in particular, the body fluctuations in postural control were noted during time to stabilisation. It became clear that to collate more information on balance strategies, data on both postural control and postural stability in a balance task was important. Two-legged balance tasks yielded neglible visible use of balance strategies so the ABS test was developed for one-legged balance tasks in line with findings from published research. Observation data were divided into three sections of criterion for the body: arms, legs and spine and the criterion of time to stabilise; loss of control was added with an explanation of the non-support foot touching the ground. The body criterion was evaluated using a Lickert scale of 1-5.

Score descriptors were applied to the scale and are shown in Table 8.1. Time to stabilise was measured in seconds and the data could be taken from the clock on the film footage. Prior to its application in the present study, the Accumulation Balance Score criterion and scoring descriptors underwent two reviews and subsequent modifications following pilot tests, scored by assessors with over fifteen years of experience in assessing movement. Modifications included the application of feedback from the assessors and researchers after an academic presentation of the early tool.

Table 8.1 *Accumulation Balance Score: Definition of scores*

Arms score	**1**	**2**	**3**	**4**	**5**
	No movement or very minor adjustment (low level)	Controlled movements with one/ both arms moving with minor adjustment only; adjacent to waist (low level)	One arm moving quickly with the other arm held in a controlled manner	Controlled movements with one/both arms moving quickly and with major adjustment; adjacent to shoulders (middle level)	One/both arms moving rapidly; out of control
Legs score	**1**	**2**	**3**	**4**	**5**
(Support leg and/or non-support leg)	No movement or very minor adjustment in the supporting leg and/or the non-supporting leg	Controlled movements with minor adjustment in the supporting leg and/or the non-supporting leg	Quick adjustments with more separation of legs in aligned position; non-support leg may separate from support leg but remains in close proximity.	Controlled movements with one/both legs moving quickly and with major adjustment	One/both legs moving with uncontrolled, rapid movements of the non-support leg
Spine score	**1**	**2**	**3**	**4**	**5**
	No movement or very minor adjustment; vertical alignment	Controlled movement with minor adjustment; vertical or near vertical alignment	Some fluctuations of movement; near vertical alignment (predominately closer to 0˚)	Moving in a controlled manner; alignment between 0˚-45˚ on a vertical axis	Rapid fluctuations of movement; alignment beyond 45˚ on a vertical axis
Time to stabilise (seconds):			**Loss of control; non-support leg placed on ground: (Tick if applicable)**		

8.2.3 Procedures

The pre-recorded footage of jump landings was re-organised into a randomised order and separate copies of the clips were handed to the raters with the scoring sheets (see Appendix 13.14), the criteria and score descriptors. They were given instructions on the sheets and asked to follow the scoring guidelines (Table 8.1). The raters completing scores twice for intrarater analsysis were asked to leave at least 24 hours between assessments.

8.2.4 Data analyses

Intraclass correlation coefficient (ICC) is a well recognised reliability index in inter-rater and intra-rater reliability analyses (Koo and Li, 2016). Inter-rater reliability refers to variation between two or more raters who measure the same group of participants. Intra-rater reliability refers to variation of data measured by one rater across two or more trials (Shrout and Fleiss, 1979; McGraw and Wong, 1996). Using an ICC model for two-way random-effects the data was examined for a mean rating of multiple raters (k=3) (Shrout and Fleiss, 1979; McGraw and Wong, 1996) for interrater interpretation. An absolute-agreement, two-way mixed-effects, was employed for assessing intrarater reliability (Shrout and Fleiss, 1979; McGraw and Wong, 1996). Confidence intervals (95%) were calculated for all ICCs. A test-retest was also conducted and indicated good reliability: $r=0.96$, $n=288$, $p<.005$. All analyses were conducted in SPSS 26 (IBM Corporation, Chicago, Ill). ICC values less than 0.5 represents poor reliability; 0.5 to 0.75, moderate reliability; 0.75 to 0.9, good reliability; greater than 0.9, excellent reliability (Portney and Watkins, 2000). Spearman's Rank Order Correlation (rho) was selected for correlational analysis of the ABS and other recognised dynamic balance tests tested in Chapter 4 (SEBT, Pirouette, Airplane). The strength of the value of the correlation coefficient (rho) was determined by Cohen's (1988) guidelines and interpreted based on the following scale: 0.10 to 0.29 (small), 0.30-0.49 (medium), 0.50 to 1.0 (large).Statistical significance was set at $p<0.05$ using the SPSS 26 (IBM Corporation, Chicago, Ill).

8.3 Results

Results indicated an excellent inter-rater reliability for the scoring the ABS measures showing the average measure of ICC=.963, (CI=.950,.974). The intra-rater reliability of scoring the ABS measures was excellent, rater 1: ICC= .992, (CI=.988,.995) and rater 2: ICC=.989, (CI=.984,.993). Spearman's correlations for all test variables are presented in Table 8.2. The only statistically significant correlation between ABS and other field tests was shown for SEBT 0˚ and the ABS composite score (leg, arm, spine) suggesting a moderate to strong relationship between the two ($r = 0.559$, $p < 0.05$). The strongest correlations were shown for SEBT 225° and SEBT 270° ($r=.847$, $p<.0005$), SEBT 180° and SEBT 225° ($r=.837$, $p<.0005$), ABS leg and ABS spine ($r=.804$, $p<.0005$) and SEBT 135° and SEBT 180° ($r=.792$, $p<.0005$). Further strong to moderate relationships were shown between some SEBT directions, Turn (pirouette) and some SEBT directions, and between ABS arm and leg, and ABS arm and spine (see Table 8.2).

Table 8.2 *Spearman's correlation analysis between field tests and Accumulation Balance Score*

	SEBT 0°	SEBT 45°	SEBT 90°	SEBT 135°	SEBT 180°	SEBT 225°	SEBT 270°	SEBT 315°	Turn	Airplane	ABS arm	ABS leg	ABS spine	ABS com
SEBT 0°	-	.551*	.522*	.471*	.352	.374	.442	.348	-.388	.029	.050	.003	-.009	.559*
SEBT 45°	-	-	.747**	.634**	.395	.184	.176	.119	-.234	-.110	-.294	-.302	-.319	.056
SEBT 90°	-	-	-	.628**	.429	.301	.150	-.204	-.123	-.011	-.093	-.322	-.124	.005
SEBT 135°	-	-	-	-	.792**	.719**	.668**	.359	-.433	-.320	-.104	-.079	.135	.032
SEBT 180°	-	-	-	-	-	.837**	.742**	.443	-.526*	-.239	-.156	-.008	.145	.300
SEBT 225°	-	-	-	-	-	-	.847**	.423	-.595**	-.121	.064	.093	.255	.252
SEBT 270°	-	-	-	-	-	-	-	.715**	-.613**	-.351	-.070	.077	.223	.322
SEBT 315°	-	-	-	-	-	-	-	-	-.529*	-.311	-.176	.017	.089	.266
Turn	-	-	-	-	-	-	-	-	-	-.021	.271	-.184	-.213	-.243
Airplane	-	-	-	-	-	-	-	-	-	-	-.111	.097	.019	.299
ABS arm	-	-	-	-	-	-	-	-	-	-	-	.474*	.554*	.007
ABS leg	-	-	-	-	-	-	-	-	-	-	-	-	.804**	.291
ABS spine	-	-	-	-	-	-	-	-	-	-	-	-	-	.072
ABS com	-	-	-	-	-	-	-	-	-	-	-	-	-	-

SEBT = Star Excursion Balance Test; ABS = Accumulation Balance Score

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

8.4 Discussion

The aim of this study was to develop a novel balance scoring test and assess the interrater and intrarater reliability, and the validity of the test. Excellent reliability was found between raters and for single raters as per the classification of Portney and Watkins (2000). The balance indicators used in the development of the ABS test were based on observational analysis of dancers performing a battery of dance-specific balance tasks. The indicators reflect balance strategies of body sections (arms, legs, and spine). The hip, knee and ankle have been assessed previously for instability (Cloak *et al.,* 2010) and balance strategies (Kiefer *et al.,* 2011). These body sections were selected because they are more easily visible in field testing and filmed work, and can demonstrate a range of strategies including countermovement of limbs, minor to major adjustments, fluctuations from vertical alignment, and controlled to out of control movements. The test also records the time to stabilise that can be examined in relation to the postural control adjustments and this enables a greater understanding of the body adjustments made when trying to stabilise on a balance task. The correlational analysis between the ABS and other dynamic balance field tests only revealed one moderate to strong correlation between SEBT 0° and ABS composite score. This may be due to the similar position of SEBT 0° to the single limb jump landing position on which the ABS was applied. However, significant validity was not noted in terms of the other ABS indicators (arms, legs, and spine). This relates to the earlier findings of weak correlations between the various balance tests in Study 1 (Chapter 4). Although the analysis of associations between tests in Chapter 4 showed weak relationships between a number of different balance tests, the moderate to strong relationship between SEBT 0° and ABS composite score indicates that dancers who demonstrate good balance ability in one test may perform well in the other. In addition, the score design enables balance tasks to be assessed in dance sequences and could be applied to dance performances and assessments.

This test allows for an accumulation of responses in a balance task to be recorded. This is essential for building up a more complete bank of information to help us understand dancers' control of complex movements (Bläsing *et al.,* 2012) and the variablility in their responses to balance challenges. It would be unwise to assume this test would define which balance tasks are better suited to challenge dancer's balance performance but it could be useful in assessing more details of variability. This new test contributes information in independent application or in conjunction with other test data, supplementing analysis on variability, proprioception, and organisation of postural control and stability responses-both reactive and predictive (Pollock *et al.,* 2000).

Strengths and limitations

To the best of our knowledge, this is the first balance scoring assessment designed specifically to record data from novel dance-specific tasks. This is an important development in balance research in dance as, uniquely, it allows assessment of balance tasks in continuous sequences, and captures data on both postural stability and control which enables further investigation of reactive and predictive responses. Furthermore, it can be applied to any dance genre and in multiple settings such as field tests and performances. The test has excellent interrater and intrarater reliability. It may be assumed there are methodological limitations. There was a small sample size and the test needs to be replicated to reduce study limitations (Koo and Li, 2016). Some modifications to the ABS score descriptors and the scoring sheets may be required in further applications. These may include the loss of control indicator to be added as a column and further definition for the actions of the non-support and support leg in response to raters' feedback.

8.5 Conclusion

In conclusion, the Accumulation Balance Score has demonstrated excellent interrater and intrarater reliability, and could be a useful tool to assess postural control and responses in a wide range of field test environments. Statistically significant validity was not noted for the ABS components, although the ABS composite score was shown to have a moderate to strong relationship to SEBT 0°. Specifically, the Accumulation Balance Score is suited to assess dancers in novel extended test sequences replicating performance and spontaneous dance-specific tasks.

9 Study 6: Balance training differences on dancers' dynamic postural stability: A randomised controlled trial

9.1 Introduction

Previous chapters have drawn attention to dancers' use of balance strategies and adaptations thought to occur in balance testing. The literature on dancers' balance ability in different conditions remains inconclusive as revealed in Chapter 3, and study 2 (Chapter 5) indicated only low to moderate associations between balance and dance performance. It can be suggested, therefore, that regular dance training in class may not provide adequate training for expert balance tasks and that dancers'adaptations may limit the level of balance performance. Balance is an integral part of dance training and predominately takes place in the codified technical sequences in class work; this is often regarded as adequate training for balance skills. However, dance training effects on motor learning or within regions involved in dance processing remain inconclusive (Burzynska *et al.*, 2017). To execute balance tasks efficiently, dancers employ a range of postural control strategies (Schmit, Regis and Riley, 2005). Whilst the use of strategies is inherent in the act of balancing, and dancers have been described as experts in this role (Bläsing *et al.*, 2012), an over reliance on some strategies can result in misalignment, increased risk of injury, and masking of technical or physiological weaknesses. This presents the question of how far codified techniques can improve postural sway and balance performance or whether supplementary balance training might improve these factors and reduce risks of poor technique and injury.

Supplementary training for dancers usually includes balance tasks in their technique training. The focus often is on proprioceptive training which has been noted to improve motor skills (Bläsing *et al.*, 2012; Krasnow and Wilmerding, 2015). However, there is inconslusive evidence of the effects on balance due to a lack of testing. Tests are generally those designed for sport and may not be sensitive enough to examine the variabilities in dancers' balance performance (Koutedakis, Stavropoulos-Kalinoglou and Metsios, 2015). Current tests do not gather data on both postural stability and control which would be valuable for analysis on the reported superior perceptual-motor skill of dancers (Stins *et al.,* 2009), nor do they replicate complex dance movements such as pirouettes which require control of a turning axis (Golomer *et al.,* 2009a).

There is limited research on balance training for dancers. Vibration training increased static stability and SEBT scores in dancers exhibiting ankle instability in a randomised controlled trial by Cloak and colleagues (2010). A study by Hutt and Redding (2014) assessed a dance-specific eyes-closed training programme on adolescent ballet dancers. The intervention took place in class and consisted of sequences of codified ballet steps. Measurements were taken for speed, reach, and sway on modifications (time and reach) of the SEBT and some improvements were seen for speed and reach, although methodological limitations were noted by the researchers. Other balance training interventions have included supplementary training rather than in-class interventions. A core-stabilisation intervention was found to significantly improve anterior reach distances in the modified SEBT, with less improvement in *passé relevé* and the number of pirouettes, in a study on competitive collegiate dancers (Watson *et al.*, 2017). Proprioceptive training significantly improved dynamic balance in all the tests in a study on sport dance dancers (Ljubojević *et al.*, 2012). The training intervention in this study comprised of a range of tasks with different task difficulty, and surface and vision conditions, and the tests included single and double leg balances with different vision conditions. Tekin, Agopyan, and Baltaci (2018) who conducted a proprioceptive-neuromuscular intervention on modern dance university students found similar results in a study. These last two studies concluded that dance technique classes do not alone provide enough training to enhance balance performance, and that this is primarily due to the fact that classes are designed to increase skill acquisition. Therefore, supplementary balance training is suggested as a necessary factor in improving balance performance.

The above studies assessed balance using a variety of tests similar to those used in previous research on dance populations. However, the tests in these studies on balance training may not be fit for purpose, in terms of measuring different aspects of postural control in an expert population. Only three studies, to date, have assessed dancers from the theatrical dance genres (Cloak *et al.,* 2010; Hutt and Redding, 2014; Tekin, Agopyan and Baltaci, 2018), and in two of these studies, the intervention design consisted of codified dance movements (Hutt and Redding, 2014; Tekin, Agopyan and Baltaci, 2018), although Tekin and colleagues (2018) added perturbation and resistance tasks. In contrast, it is not known whether more spontaneous tasks such as improvised movements might disrupt dancers' normal reactive responses, eliciting greater training effects.

Therefore, the aim of this study was to examine balance training differences on dancers' dynamic postural stability in a randomised controlled trial, comparing the effects between in class improvisation training, supplementary training, and technique training alone (control), and employing the Accumulation Balance Score. It was hypothesised that in class training and supplementary training would not elicit differences in dancers' balance performance.

9.2 Method

9.2.1 Study design:

This randomised controlled study examined balance training differences on dancers' dynamic postural stability. The three groups for testing were in-class training, supplementary training and control.

9.2.2 Participants

A sample size of 42 participants was required based on calculations using previously reported data (Ljubojević *et al.,* 2012) and assuming an 80% power with an alpha level of 5%, ES 0.25. A higher number were recruited because of attrition rates. The total of 56 dance undergraduates participated in the study (F=51; age: 20±1.48 yrs; height: 165.25±7cm; mass: 65.92±9.63 kg;

M=6; age: 22±5.98 yrs; height: 173.9±4.34cm; mass: 81.4±8.99 kg; dance experience: 9.21±5.16 years). All participants were studying on undergraduate performing arts programmes in the same institution and received equal hours of training in contemporary, ballet, jazz and improvisation. Inclusion criteria specified that they attended dance classes for a minimum of 8 hours per week, were injury free, and that they were 18 years or older. Prior to testing, participants completed a pre-activity health questionnaire and those with a known injury or illness were excluded. Participants signed an informed consent. The study was approved by the University of Wolverhampton ethics committee. Using a Random Generator tool, participants were randomly assigned to one of three groups: in-class training (ICT) (n = 24), supplementary training (ST) (n = 16), and control (C) (n = 16).

9.2.3 Measures

Participants were tested pre- and post-training for postural stability in a novel dance sequence which had indicated high test-retest reliability: r=.99, n=368, p<.005. The test protocol included four dynamic single-stance, dance-specific, balance challenges with a duration of four seconds each. Single-leg stance has been shown to be challenging for dancers (Watson *et al.*, 2017), and balance tasks using dance positions have restricted the duration to a few seconds (Lin *et al.*, 2005; Morrin and Redding, 2013). The sequence used movements from the contemporary dance genre and was created to be a continuous piece of choreography to replicate dance performance. The collection of data met guidelines for reducing study limitations and risk of bias (Guyatt *et al.*, 2011). The pre- and post-test dance sequence consisted of 8 bars of 4 counts and lasted 34 seconds. A set piece of music was used for all performances of the test to ensure accuracy and parity in timing. A 1.5m length of tape was fixed on the floor for a reference point for measurement purposes on Dartfish, however, as it was not visible at all times due to the moving camera, a ballet barre (1.5m) was placed at the back as a further reference point for measurement of the length of the sideways jump using Dartfish analysis (Watson *et al.*, 2017).

The sequence included a turn, jumps, floorwork and four dynamic balances and transitional movements to replicate dance sequences in class and performance. The movement sequence for the four balances was as follows: (1) single turn into a step and *arabesque* and then continuous movement with gesture leg into a *developpé devant*, (2) step and jump (side hop) into *plié* and rise, (3) roll on floor (on hips) and step up into single stance *allongé* (flat back balance) moving into upright stance with arms above head and gesture leg in *retiré*, (4) side jump from two to one foot (*sissone ouverte*) instructed "travel as far as you can", arms kept low and maintain balance on landing with gesture leg in low extension to side. Specifically, the four sections of each balance selected for further analysis were collected at the following points of the balance task: (1) from the start of the *arabesque* into *developpé*, (2) from the moment of landing into a rise, (3) from the start of the *allongé* into upright stance, (4) from moment of landing with gesture leg held out to side. Using Dartfish analysis (Watson *et al.,* 2017), postural stability was measured by the duration of the balance (0-4 seconds); in addition, the jump into Balance 4 was a potential disruption to postural stability and therefore the jump distance also was measured; all balance tasks were observed for accuracy. Secondly, the Accumulation Balance Score (see Chapter 8) was applied and postural control measures were taken for arms, legs and spine in each of the four performed balances.

9.2.4 Procedures

Balance sequence test

All participants completed a standardised 15-minute cardiovascular warm up including jogging, skipping and gallops prior to data collection. The test sequence was taught by the researcher and participants were given enough time to practise the sequence to ensure accuracy in performance. The participants were blinded to the aims of the study. The sequence was performed in groups of four or five participants at a time to maintain safe practice in the studio and all tests were filmed for further analysis. The set music accompaniment was used for all tests. Data were recorded on film for Dartfish analysis to measure time for balances 1-4 and distance for balance 4 (Watson *et al.*, 2017). The Accumulation Balance Score (ABS) was applied to measure postural stability and postural control as outlined in Chapter 8.

Training

Participants in the ICT and ST experimental groups took part in twice-weekly training protocols during the four-week intervention period. Each protocol session took place at the same time each week. Participants in the ST group undertook a warm-up for ten minutes if they were not warm from a prior class. The relevant protocols were explained before the start of the 4-week intervention, and participants in the ST group were able to practise the balance tasks for familiarisation purposes. There was a recovery time of 48 hours between sessions. All participants continued their normal dance classes throughout the study.

In class training

Prior to the study, the participants' dance lecturers leading the in-class training (ICT) were given the protocol guidelines with a sheet of instructions for each of the eight sessions (see 13.6-13.13). The randomised order of balance tasks and the randomised start time of each balance for each session were recorded on the sheets. The training took place immediately after the class warm up to ensure consistency. The ICT group performed two novel, dance-specific training protocols per week. The protocol consisted of a continuous two-minute improvisation during which time there were four balance commands given by the dance lecturer. Prior to each training session, participants were given instructions to follow the balance commands as quickly as possible and to try to maintain the given balance task until they were instructed to start moving again. All balances were single leg stance with eyes open. The four balance commands were as follows: "right leg flat", "left leg flat", "right leg demi", "left leg demi". The term "flat" related to balancing on a flat foot, and "demi" referred to a balance on demi pointe (ball of the foot). The duration of each balance task was five seconds, after which participants were given the command "go" and they continued to improvise until the next balance command or the final command to stop. In weeks 3-4, the balance time was increased to 7 seconds and participants were instructed to keep moving their non-support bearing leg and arms during the flat foot balances to increase perturbation. All in class training sessions were timed with a stopwatch.

Supplementary training

The ST group performed a circuit of five tasks in a randomised order. Weeks 1-2: (1) Lunge step and return to single stance balance using the Star Excursion Balance Test (SEBT) reach directions: The SEBT is a dynamic balance test utilising a grid comprising 8 lines marked on the floor, extending from a common point at 45˚ angle increments (Gribble *et al.,* 2013) as described in Chapter 4. This task was modified from the SEBT protocols as previous research has indicated that the SEBT protocol may provide limited challenge to dancers (Armstrong *et al.,* 2018). Participants were instructed to place their standing foot aligned to the centre of the grid of the 8-line star and perform a lunge step reaching as far as possible along the line in each direction. As weight was transferred to the lunge step on flat foot, the standing foot on the centre of the grid had to release from the floor. After each lunge step, the participants were instructed to return to a single stance flat foot balance with the standing foot aligned to the centre of the grid. Participants were asked to stabilise as quickly as possible and maintain the balance for a total of 3 seconds. Two sets (all directions) were performed on each side. (2) Triple hop sequence for distance ending in flat foot balance: The single leg triple hop is a reliable tool which employs balance components (Hamilton *et al.,* 2008) and has been used as a more challenging task for dancers (Ambegaonkar *et al.,* 2018). A starting line was marked with tape and a cloth tape measure was fixed to the floor perpendicular to the start line to mark out the line of direction. Prior to starting the hop sequence, participants stood on their weight bearing leg, placing their big toe on the start line. They were instructed to perform three consecutive maximal hops and maintain a single leg balance on the third landing for 3 seconds as previously reported (Barber-Westin, 2018). Three sets were completed for each leg 3 sets per leg. (3) Modified Romberg test with eyes closed (30s duration) (Richardson *et al.*, 2010); 2 sets per leg. (4) Horizontal side jump taking off from two feet and landing on one foot ending in a balance (3s duration); 3 sets per leg. (5) Four single leg balance tasks on a vibrating wobble board (Vibrosphere) (ProMedvi, Sweden). Comined vibration and wobble board training has been associated with increased proprioception (Cloak et al., 2013) (Figure 9.1). Adaptations were made to tasks with increased difficulty, with dance-specific tasks replacing sport-specific tasks. The tasks included a static balance, rises, *developpés*, and *demi-pliés* (Table 9.1). Each balance task was 45s duration (30Hz) (Cloak *et al.*, 2013). Although previous studies had increased the difficulty of the function pad after two weeks (Cloak *et al.*, 2013), this study increased the function pad level of difficulty after one week as ST participants did not experience any perturbation challenges when using the first intermediate level function pad. In weeks 3-4, modifications to increase task difficulty were as follows: (1) In the SEBT task, the balance task at the end of each lunge and return to the centre was performed on demi pointe, rising to this position as soon as possible from the flat foot. (2) In the triple hop task, the balance was on demi pointe, rising as soon as possible from flat foot. (3) The modified Romberg balance duration increased to 60s. (4) The Vibrosphere exposure time increased to 60s (35Hz), and arm tasks and more challenging function pads were used (Cloak *et al.*, 2013) (Table 9.1).

Figure 9.1 Participant on Vibrosphere

Table 9.1 *Vibrosphere training protocols*

Wk 1	Exercise	Difficulty	Function Pad	Time	Hertz
	Standing on 1 leg	Static, hands on hips	Dark blue-soft 2-intermediate	2 x 45s each leg	30
	Heel raises on 1 leg	Dynamic, with support	Dk blue	2 x 45 each leg	30
	Developpés (unfolding gesture leg) forward, standing on 1 leg	Dynamic, hands on hips	Dk blue	2 x 45 each leg	30
	Demi pliés (knee bends) standing on 1 leg	Dynamic, hands on hips	Dk blue	2 x 45 each leg	30
Wk 2	Standing on 1 leg	Static, hands on hips	Red-soft 3-difficult	2 x 45s each leg	30
	Heel raises on 1 leg	Dynamic with support	Red-soft 3-difficult	2 x 45s each leg	30
	Developpés forward, standing on 1 leg	Dynamic, hands on hips	Red-soft 3-difficult	2 x 45s each leg	30
	Demi pliés standing on 1 leg	Dynamic, hands on hips	Red-soft 3-difficult	2 x 45s each leg	30

Wk 3	Standing on 1 leg	Dynamic, arms circles (anterior-posterior)	Red-soft 3-difficult	2 x 60s each leg	35
	Heel raises on 1 leg	Dynamic with support	Red-soft 3-difficult	2 x 60s each leg	35
	Developpés forward and side, standing on 1 leg	Dynamic, arm movements from anterior to side	Red-soft 3-difficult	2 x 60s each leg	35
	Demi pliés standing on 1 leg	Dynamic, arm movements to side and down	Red-soft 3-difficult	2 x 60s each leg	35
Wk 4	Standing on 1 leg	Dynamic, arms circles (anterior-posterior)	Blue-challenging fitness pad	2 x 60s each leg	35
	Heel raises on 1 leg	Dynamic with support	Blue-challenging fitness pad	2 x 60s each leg	35
	Developpés forward and side, standing on 1 leg	Dynamic, arm movements from anterior to side	Blue-challenging fitness pad	2 x 60s each leg	35
	Demi pliés standing on 1 leg	Dynamic, arm movements to side and down	Blue-challenging fitness pad	2 x 60s each leg	35

9.2.5 Data analyses

Analyses of balance tasks (time and distance) was via Dartfish measurement assessments (Watson *et al.,* 2017), and postural control (arms, legs, spine) on the Accumulation Balance Score (ABS) as outlined in 9.2.3. The dependent variables were Balances 1-4 (time, and arms, legs, spine) and Balance 4 (distance). A repeated measures factorial MANOVA was conducted over time by group with a hypothesis that one group improve more than other groups. Individual participant's difference between pre and post training were calculated for each dependent variable before statistical analysis was conducted to compare the effects of balance training on postural stability. Bonferroni post hoc were used to determine the between group differences. Statistical significance was set at $p<0.05$ using the SPSS 20 (IBM Corporation, Chicago, Ill). Secondly, the Accumulation Balance Score (ABS) was applied to the footage of tests on Dartfish. The dependent variables were arms, legs, spine, and time for all Balances 1-4 (see Chapter 8). A one-way between-subjects ANOVA was conducted to compare the effects of balance training on postural stability and postural control. Effect sizes were determined by eta-squared, and Cohen's guidelines (1988) interpreted based on the following scale: 0.01 (small), 0.06 (medium), 0.14 (large). Post hoc tests were used to determine the between group differences.

9.3 Results

Results from the pre- and post-test descriptive statistics for stability (time and distance) are presented in Table 9.2 and show that Balance 2 (B2) (jump landing to rise) had the lowest mean and the highest standard deviation (SD) from the mean. The largest increase in the mean (so improved postural stability) was shown for the ICT group for Balance 2. There were lower SD results for the B2 pre-post ICT group and B2 post-test ST group. For Balance 4 (B4) (distance), the post-test ST group showed the largest increase in mean value.

Table 9.2 *Pre- and post-test descriptive statistics for balances 1-4 (Time) and balance 4 (Distance)*

Test	Group	N	Pre-test Mean ± SD	Post-test Mean ± SD	Change
Balance 1 (secs)	In-class training	16	3.50±0.73	3.94±0.25	0.44
	Supplementary Training	16	3.88±0.34	3.87±0.50	0.01
	Control	24	3.63±0.82	4.00±0.00	0.37
Balance 2 (secs)	In-class training	16	2.19±0.75	3.19±1.05	1.00
	Supplementary Training	16	2.94±1.06	3.69±0.79	0.75
	Control	24	2.42±1.06	2.54±1.02	0.12
Balance 3 (secs)	In-class training	16	3.69±0.70	3.69±0.79	0.00
	Supplementary Training	16	3.81±0.40	4.00±0.00	0.19
	Control	24	3.21±1.10	3.67±0.76	0.46
Balance 4 (secs)	In-class training	16	3.63±0.81	4.00±0.00	0.37
	Supplementary Training	16	3.62±0.72	3.94±0.25	0.32
	Control	24	3.46±1.02	3.83±0.48	0.37
Balance 4 Distance (cm)	In-class training	16	58.56±22.83	73.13±22.80	14.57
	Supplementary Training	16	51.25±18.78	82.19±30.26	30.94
	Control	24	51.96±16.50	69.09±26.17	17.13

The mean, SD and 95% CI for the groups' performances in Balances 1-4 are shown in Table 9.3 with the C and ST groups showing the greatest difference in B4 (distance).

Table 9.3 *Mean, Standard Deviation and 95% Confidence Interval of Groups in Balances 1-4*

Test	Group	Number	Mean ± SD	95% CI
B1 diff	Control	24	0.38±0.82	(.03,.72)
	In-class	16	0.44±0.81	(.00,.87)
	Supplementary Training	16	0.00±0.63	(-.34,.34)
	Total	56	0.29±0.78	(.08,.49)
B2 diff	Control	24	0.13±1.15	(-.36,.61)
	In-class	16	1.00±1.32	(.30,1.70)
	Supplementary Training	16	0.75±0.85	(.29,1.21)
	Total	56	0.55±1.17	(.24,.87)
B3 diff	Control	24	0.46±0.97	(.05,.87)
	In-class	16	0.00±1.15	(-.62,.62)
	Supplementary Training	16	0.19±0.40	(-.03,.40)
	Total	56	0.25±.91	(.00,.50)
B4 diff	Control	24	0.38±1.21	(-.14,.89)
	In-class	16	0.38±0.80	(-.05,.80)
	Supplementary Training	16	0.31±0.79	(-.11,.74)
	Total	56	0.36±0.98	(.09,.62)
B4 cm diff	Control	24	5.71±18.96	(-2.30,13.72)
	In-class	16	14.56±20.95	(3.40,25.73)
	Supplementary Training	16	30.94±28.46	(15.77,46.10)
	Total	56	15.45±24.54	(8.87,22.02)

An analysis of variance showed the effect of balance training on B2 was significant: $F(2,53)=3.21$, $p=0.04$ and the effect of balance training on B4 (distance) was significant: $F(2,53)=6.01$, $p=0.004$. The actual difference in mean scores between the groups was quite small. Effect sizes calculated using eta squared were small for B2 (.10) and B4 (distance) (0.18). A

Bonferroni test further indicated statistically significant differences between the C and ST groups in the B4 (distance). There were no significant effects of balance training on B1 ($p=0.22$), B3 ($p=0.29$), or B4 ($p=0.988$).

Results from the pre- and post-test descriptive statistics for the specific components of the ABS are shown in Table 9.4. The higher the mean score for arms, legs, spine, the more fluctuations or adaptations were shown in postural control, whereas, the higher mean scores for time indicated improved stability. In terms of the arm/leg/spine scores, B2 legs show the highest mean in pre- and post-tests for all groups, although a decrease in the mean is shown for the post-test B2 legs for the ST group. The next highest mean is for B3 legs in pre- and post-tests for the CT group, B4 legs in pre- and post-tests for the CT group, and B4 spine in post-tests for the ICT and CT groups. In the post-test results, the largest decrease in mean value for postural control movements (arm/legs/spine) are shown for the ST and ICT groups in B2 legs, followed by the ST group for B4 legs and B4 spine. The greatest increase for time (stabilisation) were shown in B2 and B4 mean values for the aforementioned groups. Thus, ABS results indicated that training (ICT and ST groups) had the greatest effect on the B2 task with improved stability and less fluctuations of movements in legs in the post-tests. This was followed by the effect of training (ST group) on the B4 task with improved stability and less fluctuations in legs and spine in post-tests.

Table 9.4 *Pre- and post-test descriptive statistics for Balances 1-4 using the Accumulation Balance Score*

Test	Group	N	Pre-test±SD	Post-test±SD	95% CI Pre-test	95% CI Post-test
B1 arms	In-class training	16	1.12±0.34	1.19±0.54	(.94,1.31)	(.90,1.48)
	Supplementary training	16	1.00±0.00	1.00±0.00	(1.00,1.00)	(1.00,1.00)
	Control	24	1.21±0.41	1.04±0.20	(1.03,1.40)	(.95,1.13)
Bl legs	In-class training	16	1.37±0.81	1.19±0.40	(.94,1.80)	(.97,1.40)
	Supplementary training	16	1.12±0.50	1.00±0.00	(.86,1.40)	(1.00,1.00)
	Control	24	1.54±0.83	1.40±0.50	(1.19,1.89)	(1.17,1.60)
B1 spine	In-class training	16	1.06±0.25	1.00±0.00	(.93,1.20)	(1.00,1.00)
	Supplementary training	16	1.00±0.00	1.00±0.00	(1.00,1.00)	(1.00,1.00)
	Control	24	1.08±0.28	1.04±0.20	(0.96,1.20)	(.95,1.13)
B1 time	In-class training	16	3.50±0.73	3.94±0.25	(3.11,3.89)	(3.80,4.07)
	Supplementary training	16	3.90±0.34	3.87±0.50	(3.70,4.06)	(3.61,4.14)
	Control	24	3.62±0.82	4.00±0.00	(3.28,4.00)	(4.00,4.00)
B2 arms	In-class training	16	1.19±0.40	1.06±0.25	(1.00,1.40)	(.93,1.19)
	Supplementary training	16	1.10±0.25	1.12±0.34	(.93,1.20)	(0.94,1.31)
	Control	24	1.42±0.60	1.62±0.92	(1.20,1.70)	(1.23,2.01)
B2 legs	In-class training	16	3.25±0.86	2.37±1.09	(2.80,3.71)	(1.80,2.95)
	Supplementary training	16	2.90±1.02	1.50±0.73	(2.33,3.42)	(1.11,1.89)
	Control	24	3.33±0.92	3.12±1.07	(2.95,3.72)	(2.67,3.57)
B2 spine	In-class training	16	1.31±0.60	1.12±0.34	(1.00,1.63)	(.94,1.31)
	Supplementary training	16	1.40±0.62	1.19±0.40	(1.04,1.70)	(.97,1.40)
	Control	24	1.33±0.56	1.62±0.92	(1.10,1.60)	(1.23,2.01)
B2 time	In-class training	16	2.19±0.75	3.19±1.05	(1.79,2.59)	(2.63,3.74)
	Supplementary training	16	2.94±1.10	3.69±0.79	(2.40,3.50)	(3.26,4.11)
	Control	24	2.42±1.06	2.54±1.02	(1.97,2.90)	(2.11,2.97)
B3 arms	In-class training	16	1.10±0.25	1.31±1.01	(.93,1.20)	(.77,1.85)
	Supplementary training	16	1.12±0.50	1.06±0.25	(.86,1.40)	(.93,1.20)
	Control	24	1.12±0.34	1.17±0.64	(1.00,1.26)	(.90,1.43)
B3 legs	In-class training	16	2.10±1.24	1.87±1.20	(1.40,2.72)	(1.23,2.52)
	Supplementary training	16	1.44±0.90	1.69±0.87	(.96,1.91)	(1.22,2.15)
	Control	24	2.25±1.22	2.17±1.17	(1.73,2.77)	(1.67,2.66)
B3 spine	In-class training	16	1.00±0.00	1.31±1.01	(1.00,1.00)	(.77,1.85)
	Supplementary training	16	1.12±0.34	1.06±0.25	(.94,1.30)	(.93,1.20)
	Control	24	1.12±0.45	1.10±0.41	(.93,1.31)	(.91,1.25)
B3 time	In-class training	16	3.69±0.70	3.69±0.80	(3.31,4.06)	(3.26,4.11)
	Supplementary training	16	3.81±0.40	4.00±0.00	(3.60,4.03)	(4.00,4.00)
	Control	24	3.21±1.10	3.67±0.76	(2.74,3.70)	(3.34,3.99)
B4 arms	In-class training	16	1.25±0.45	1.44±1.03	(1.01,1.49)	(.89,1.99)
	Supplementary training	16	1.25±0.70	1.00±0.00	(0.89,1.61)	(1.00,1.00)
	Control	24	1.25±0.61	1.46±0.66	(1.00,1.51)	(1.18,1.74)
B4 legs	In-class training	16	1.81±0.91	1.62±1.08	(1.33,2.30)	(1.04,2.20)
	Supplementary training	16	2.06±1.24	1.44±0.51	(1.40,2.72)	(1.16,1.71)
	Control	24	2.33±1.01	2.12±0.90	(1.91,2.76)	(1.74,2.50)
B4 spine	In-class training	16	1.94±0.93	2.31±1.35	(1.44,2.43)	(1.60,3.03)
	Supplementary training	16	2.06±1.12	1.37±0.62	(1.46,2.66)	(1.04,1.70)
	Control	24	1.92±0.93	2.37±1.20	(1.52,2.31)	(1.86,2.88)
B4 time	In-class training	16	3.62±0.81	4.00±0.00	(3.19,4.05)	(4.00,4.00)
	Supplementary training	16	3.62±0.72	3.93±0.25	(3.24,4.00)	(3.80,4.07)
	Control	24	3.46±1.02	3.83±0.48	(3.03,3.89)	(3.63,4.04)

An analysis of variance showed a statistically significant difference at the p .05 level on effects of balance training on B1 leg: $F(2,53)=4.4$, $p=.016$, B2 arm: $F(2,53)=4.6$, $p=.014$, B2 leg: $F(2,53)=12.8$, $p=.001$, B2 spine: $F(2,53)=3.3$, $p=.041$, B2 time: $F(2,53)=6.9$, $p=.002$, B4 leg: $F(2,53)=3.3$, $p=.042$, and B4 spine: $F(2,53)=4.3$, $p=.018$. The actual difference in mean scores between the groups was quite small. Effect sizes calculated using eta squared were small for B1 leg (.16), B2 arm (.17), B2 spine (.12), B2 time (.21), B4 leg (.04), B4 spine (.16) and towards medium for B2 leg (0.48). Post-hoc comparisons using the Tukey HSD test indicated significant differences between the C and ST groups in B1 leg, B2 leg, B4 leg and B4 spine, and between the ICT and CT groups in B2 arm, and ST and ICT groups in B2 leg.

9.4 Discussion

The aim of this study was to investigate the effects of balance training on postural stability and postural control in a novel and reliable dance performance test. Balance training was divided into two groups: an in-class training group with a novel dance improvisation-based training protocol and a supplementary training group with a training protocol based on a circuit of balance tasks, some of which were modified to make them more aligned to current dance practice. The results revealed some evidence to reject the null hypothesis that balance training would have no effect on balance ability. Specifically, balance training had a statistically significant effect on postural stability in Balance 2 (time), and postural control in Balance 1 (legs), Balance 2 (arms, legs, spine) and Balance 4 (legs, spine), and also Balance 4 (distance). The ICT group demonstrated the largest increase in time for Balance 2, suggesting improved postural stability in this task. The ST group showed the largest decrease in postural control movements in legs in Balance 2 indicating improved postural control. The ST group showed the greatest increase in distance jumped in Balance 4 landing on one leg, suggesting improved postural stability and postural control. There were no significant effects of balance training on Balances 1, 3 or 4 (measured in time). Between groups, a significant difference was found between the Control (C) group and

Supplementary Training (ST) group in Balance 4 (distance), between the C and ST groups in Balance 1 (leg), Balance 2 (leg), Balance 4 (leg) and Balance 4 (spine), between the ICT and ST groups in Balance 2 (arm), and the ST and C groups in Balance 2 (leg). Otherwise, the differences between groups demonstrated mixed findings in the other balance tasks and the evidence for this remains inconclusive thus far.

Effects of balance training

It might be suggested that the effect of training on the performance of Balance 2 was influenced by the physical demands of the task itself. During the tests, it was observed as one of the more challenging tasks for the participants. The task involving a side hop and landing preceding a timed rise on demi pointe may have proved more challenging than the other tasks due to the displacement of the centre of mass first sideward and then upwards. Both directions are used extensively in dance training and performance but the directional changes plus the reduced base of support on demi pointe resulted in a greater use of visible balance strategies to attempt to maintain control and stability. As discussed in earlier chapters, dancers rely on an increased proprioceptive input when balance conditions are challenged (Golomer and Dupui, 2000) and this task may have disrupted normalised balance strategies and increased kinematic variability due to its design.

The effect of balance training on the performance of Balance 4 (distance and postural control) may be due to several factors, although the evidence remains inconclusive. The task itself, a large jump to the side (*sissonne*) followed by a timed balance of the gesture leg and arms replicates dance-specific movements in the theatrical genres. However, it is possible that some participants had grown in confidence by the time the post-testing took place and felt able to rise to the challenge of the instruction to jump as far as they were able in the sideward direction. Furthermore, there was a decrease in fluctuations of leg and spine movements and participants may have utilised a greater number of balance strategies or exhibited a different organisation of postural control than in previous testing, or may have found the task less challenging, and thus relied more predominately on their dance experience and expertise. Earlier studies have employed codified dance movements in their training protocols and seen improvements in balance ability (Hutt and Redding, 2014; Tekin, Agopyan and Baltaci, 2018), but training effects and selected testing protocols may have influenced these results.

Differences between groups

The ST group demonstrated the greatest increase in the distance jumped in the Balance 4 (distance) task. It is feasible that specific factors of the balance training they undertook may have influenced their performance in this task. Task difficulty may have been reduced for this group due to a similar jump/balance protocol in their circuit of balance training protocols, and this concurs with other findings (Tekin, Agopyan and Baltaci, 2018). Furthermore, several of the balance training protocols are known to have the capacity to increase LE strength and ankle stability (Hamilton *et al.*, 2008; Cloak *et al.*, 2013). The ICT group demonstrated the greatest increase in postural stability, although there was no significant interaction effect, and the group also showed decreased movement adaptations in Balance 2, which was a challenging task for participants as shown by the balance time. (Table 9.2). This group's improvisation-based balance training may have reduced the opportunities to employ more commonly used balance strategies in the training sessions due to the unexpected and disrupted type of improvised (or "free") movements, both before and after the various balance tasks. These training balance tasks were randomised in support leg (right/left), stance (flat/demi), and timing of balances within a two-minute session (see appendices 13.6-13.13). Thus, as much disruption as possible was applied to improvised dance movement patterns and balances within a movement sequence. The ST group's decrease in postural control adaptations and increased stability in Balance 2 could be linked to training effects, resulting in enhanced use of balance strategies after a jump landing. It may be suggested that in the Balance 2 post-tests, greater reliance was placed on proprioception by ICT and ST participants, rather than their typical strategies used in class or performance. Postural control strategies have been recognised as qualitative rather than quantative in dancers, with dancers exhibiting differences in organisational patterns of postural sway and control (Schmit, Regis and Riley, 2005), and this variability should be given further consideration. There is a challenge between internal and ecological validity in the more experimental approach in the field of dance science and this study has aimed to balance this tension in its approach to replicate performance and the design of dance-specific test protocols and training adaptions, and the application of a dance-specific balance assessment tool.

Strengths and Limitations

To date, this is the first study to examine the effects of balance training on dynamic postural stability and postural control of dancers in a sustained movement sequence. Specifically, it is the first study to employ novel dance-specific training and dance-specific test protocols. The test protocol is designed as a continuous sequence including balance tasks that form part of the choreography, thus replicating dance performance. Furthermore, it is the first study to employ a dance-specific balance scoring tool. The tool which assesses both postural stability and postural control facilitates analysis of the participants' reactive and responsive responses to a balance task, and can be applied, uniquely, to movement sequences. Two of the balance tests (Balance 2 and Balance 4 time) may have provided a greater challenge for dancers, mitigating against a "ceiling" effect previously reported in dance (Burzynska *et al.*, 2017). It may be assumed that there are methodological limitations in this study. A multivariate analysis of the variables of time, distance, arms, legs and spine would have revealed the effects of the variations on each other and the impact of each variation to the final outcome. This may have affected the accurate, full reporting and interpretation of results in the study, and limited a more informed and nuanced application of findings to future testing. There was evidence of mixed ability in the cohort of participants. Although all participants had similar weekly training hours on their performing arts programmes, some had less previous experience of dance. This may have resulted in a greater range of use of balance strategies than earlier studies, as some participants may have been less proficient at utilising balance strategies, an area of expert skill in more experienced dancers. Although the novel dance test was practised before the pre- and post-tests, some participants may have taken less "risk" when attempting to meet the challenges of the balance tests. It is possible that some balance tasks in the test protocol were more challenging than others. The ST training tasks included some tasks previously used in general health and sports although these were modified to enhance the dance specificity of the tasks. The ST training intervention comprised of a combination of exercises and it is unclear if any of these had a greater effect, or not, on training effects (Zech *et al.*, 2010).

9.5 Conclusion

In conclusion, this study indicates that dance-specific balance training is effective in improving dynamic postural stability and postural control for dancers. Specifically, balance training had a significant effect on postural stability and postural control in Balance 2 and postural control in Balance 4. Statistically significant differences between groups indicated that the ST and ICT groups showed the greatest improvement in postural control in Balance 2, and the ST group the most improved distance jumped in Balance 4. The Accumulation Balance Score yielded valuable data on both postural stability and postural control allowing for analysis and greater understanding of postural balance strategies. Further investigation is recommended to examine the specific elements in the ICT and ST training protocols that may influence the findings. Novel, dance-specific training and test protocols should be replicated to limit study bias, and dance-specific balance scoring systems should be considered to enhance the interpretation of dancers' balance performance.

10 Summary discussion

10.1 Introduction

This general discussion will draw together the key findings from the research programme in the thesis, discuss the applied implications of the findings, make recommendations for future studies and conclude by addressing the research question.

The original research was posed as: are current balance assessment tools and balance training protocols effective in assessing balance ability in dancers? This laid the foundation for the key aim which was to develop a dance-specific balance tool. In order to address the question, a systematic review was conducted, followed by a series of experimental studies. These were designed firstly to examine associations between five field tests used in previous studies on dancers; secondly, to examine associations between these tests and performance ability; thirdly, to examine both the effects of bilaterality and fatigue on postural stability using a functional time to stabilisation test; fourthly, to develop a reliable, novel dance-specific balance scoring measure, and finally, to examine the effects of balance training on postural stability and postural control in a randomised controlled trial. Uniquely, the reliable balance scoring measure was developed for assessing balance ability in both lab-based test protocols and in performance. An important extension of previously established methods was to create tasks that more closely resembled dance performance, in both spontaneous form and choreographed conditions.

10.2 Summary of the main findings

The main findings can be summarised as follows. The systematic review revealed mixed findings. A number of reported effects on dancers' balance were reported, but there were no replicated studies. A wide range of assessment tools were shown but no assessment tool presented itself as providing best evidence. There were no studies on associations between balance tests or on effects of balance assessment or training on dance performance. Overall, the studies demonstrated low scores for their methodological approaches. Study 1 assessed associations between five field tests:

Star Excursion Balance Test (Gribble *et al.*, 2012), a pirouette test (Denardi *et al.*, 2008; Golomer *et al.*, 2009b; Lin *et al.*, 2011), the Airplane test (Richardson *et al.*, 2010), the modified Romberg (Rogers, 1980; Richardson *et al.*, 2010), and the Biosway^{TM} (Rein *et al.*, 2011). Overall, results showed weak correlations between the balance tests. A moderate correlation was indicated between the Biosway and SEBT 0˚ and SEBT 45˚ respectively, and strong correlations were indicated between some SEBT directions. The findings suggest that balance measures may have limited functional relevance and accuracy in assessing dancer's postural stability.

Study 2 examined associations between balance ability and dance performance. The results showed that although some tests had a predictive ability on performance, these were of a low predictive strength. SEBT 90˚ and the Romberg test were best associated with all three dance genres in technique performance, and SEBT 225˚ was best associated with all genres of repertoire performances, whilst the Romberg was the predominant predictor of successful performance. The causes for any associations cannot be ascertained from these results. The findings challenge the premise that balance ability is essential for in-house measures of dance performance.

Study 3 examined the effects of bilateral differences on dynamic postural stability during single-leg landing using a time to stabilisation protocol (Wikstrom *et al.*, 2005). Results showed no statistical difference in postural stability between legs in jump landing. Findings indicate that training does not cause lateral bias and dancers' self-perceived leg dominance does not correlate with balance ability in single leg landings.

Study 4 assessed the effects of fatigue on postural stability and the effects on bilateral leg differences in a time to stabilisation test. The Dance Aerobic Fitness Test (DAFT) (Wyon *et al.*, 2003) was selected as a means to fatigue participants to ascertain whether this would produce greater variability in dancers' postural stability. Results indicated that both fatigue nor leg differences had an effect on postural stability, and so the findings indicate that dancers may employ balance strategies to maintain stability.

Study 5 developed a unique dance-specific balance scoring measure (Accumulation Balance Score), and assessed interrater and intrarater reliability and validity of the test. Results indicated an excellent interrater reliability and intrarater reliability. These results and the design of the test suggest that it could be used to measure balance ability in both lab based tests and performances.

Finally, study 6 examined balance training differences on dancers' dynamic postural stability, in a randomised controlled trial, comparing the effects between in class improvisation training (ICT), supplementary training (ST), and technique training alone (Control). To replicate dance performance more closely, a novel, reliable dance sequence test was developed and analysis undertaken to measure postural stability and postural control. The novel Accumulation Balance Score (ABS) was applied to gather detailed data on the fluctuations of body segments when balancing. Results revealed that balance training had a statistically significant effect on Balance 1 (postural control in legs) Balance 2 (postural stability, and postural control in arms, legs, and spine) and Balance 4 (postural control in legs and spine, and distance). Statistically significant differences between groups indicated that the ST and ICT groups showed the greatest improvement in postural control in Balance 2 and the ST group the most improved distance jumped in Balance 4. The application of the ABS allowed for a more detailed analysis of postural control strategies in a dance sequence. Findings indicate that training effects can improve balance ability but the results suggest that some balance tasks may be more challenging than others for a dance population.

10.3 Limitations

It is reasonable to assume that, within the present body of work, there are a number of methodological limitations that need be considered. The balance tests used in the experimental studies may not have all posed a sufficient challenge for the participants. The SEBT and Airplane may be regarded as only moderately challenging for dancers in terms of postural stability and control and movement complexity (Armstrong *et al.*, 2018), and the Biosway^{TM} presents little challenge for dancers. It is also possible that the time to stabilisation jump test did not challenge dancers in terms of a complex task, particularly in light of the fact that the fatigue intervention did not have a significant effect on performance. In contrast, some participants may have found some tests too challenging. During observation of the testing, the pirouette test (in Studies 1 and 2), and the Balances 2 and 4 (in Study 6) were less accurately performed by a small number of participants and varying levels of expertise were evident. Collectively, the tests assessed a multiple range of elements in postural stability and control and there is no agreed definition for the wider construct of postural control or stability for dancers (Dewar *et al.*, 2017). The participants demonstrated some variability in balance strategies (Golomer and Dupui, 2000) and it is not known to what extent the strategies, such as counter movement gestures, affect the data. The participants for all studies were undergraduate dancers and varying levels of expertise were evident. Replication of the tests in a professional dance population would likely yield different results in the more challenging balance tasks.

A number of tests were not empirically validated. Pirouette tests have been employed in a number of previous studies but are not empirically validated to date. The grading of performance grades used in Study 2 were an in-house measure, although second marked and moderated to UK guidelines. Test parameters of reliable tests in the thesis were followed but the time to stabilisations parameters have not been consistent across all previous studies (Gribble, Mitterholzer and Myers, 2012). Furthermore, the exact replication of studies, including the choice of data analysis, was not often possible due to published studies often assessing a number of groups, including interventions and implementing novel adaptions which were not always clearly described. The field of dance science is relatively new and whilst the need for more replication of studies was presented in the systematic review, it was deemed to be important to challenge the assumptions of associations between tests, and secondly between balance ability and performance in the field. The choice of methodology affects the interpretation of results and this has been noted as a limitation specifically in studies 3, and 6 (chapters 6 and 9). Study 3 examined the effects of bilateral differences (with legs as independent groups noted in published research) on postural stability and this influenced the choice of data analysis. Diagrams of data distribution were added to give a more transparent reading to the findings. The addition of a multivariance of analysis on the data from both the stability and postural control data in study 6 may have yielded more details to the findings, giving a potential greater external validity to the application of the findings.

The sample size of nine participants in Study 4 is relatively small with limited statistical power and effect; otherwise, sample sizes were appropriate for studies following sample size calculations. Overall, the participants had similar levels of training and experience for Studies 1-4 but there was evidence of a greater variation of expertise in Study 6 and some participants may have been less proficient at utilising balance strategies, an area of skill in more experienced participants.

The majority of balance tasks in the present studies were those originally designed for sports and general populations and it has been suggested that balance tests do not produce demands which are challenging enough for dancers (Stins *et al.*, 2009; Burzynska *et al.,* 2017). In Study 6, the novel balance tasks set in a dance sequence were designed to increase the task difficulty and more closely resemble dance performance. However, some participants may have been more cautious when attempting to meet the challenges of the balance tests, to preserve an aesthetic quality required in dance.

10.4 Strengths of the present research and contribution to literature

The strengths of this research programme are summarised as follows: The present findings constitute a positive contribution to the existing body of knowledge as no such studies on balance have been previously conducted. Firstly, the systematic review, which is the only review of literature in the field of balance and theatrical dance, includes a detailed description of the search methodology. MeSH terms were used, in line with PRISMA recommendations (Liberati *et al.*, 2009), articles were rated (Guyatt *et al.,* 2011a; Meader *et al.*, 2014), and articles were not restricted to English language. Studies 1 and 2 are the first studies to examine associations between tests and between balance ability and performance and test assumptions in these areas. The relatively large number of volunteers could also be treated as a study strength for both studies (Meader *et al.,* 2014). A number of studies, such as Studies 3 and 4, may help limit publication bias (Guyatt *et al.,* 2011c) in terms of reporting data with no significant differences, and Study 3 includes figures showing data distribution that adheres to recent guidelines for greater transparency of data in scientific research (Weissgerber *et al.,* 2016). Study 5 met guidelines for reducing study limitations and risk of bias (Guyatt *et al.,* 2011), in the data collection and study design.

A further strength and contribution of this body of work is the use, for the first time, of studies that address the assumption that current assessment tools are appropriate for dancers who are recognised as balance experts. There is a paucity of literature in this area and the studies in this thesis contribute to the body of knowledge in the field. The strategic order of selection of field tests, functional tests on a force plate, and finally novel, reliable dance-specific balance tasks demonstrates the progression of analysis of assessment of tools for testing dancers in this programme of study. Reliable measures were employed in studies 1-4, (with the addition of a dance-specific pirouette test in Studies 1 and 2) to further address the problem of mixed findings in the literature. In contrast, Study 6, in examining effects of balance training, employed reliable novel measures that more closely replicated dance performance and arguably reduced the "ceiling effect" of current measures for testing dancers' balance (Burzynska *et al.,* 2017). The challenge between internal and external validity is evident in the more experimental and emerging field of dance science and this research has balanced both in its approach to adapt balance tasks, replicate performance and the design of dance-specific test protocols and training adaptions, and develop and apply a dance-specific balance assessment tool.

The Accumulation Balance Score (ABS) (Study 5) is the first reliable balance scoring assessment designed specifically to record data from novel dance-specific tasks. It has demonstrated excellent interrater and intrarater reliability. The ABS assesses both postural control and stability and the scoring design demonstrates the variability in responses to a balance task. This is an important development in balance research in dance as it allows assessment of balance tasks in continuous sequences. It can be applied in multiple settings such as field tests and performances. Crucially, Study 6 is the first study to examine the effects of balance training on dynamic postural stability of dancers in a sustained movement sequence using novel dance-specific training and dance-specific test protocols. The application of the ABS in the analysis of data enabled scrutiny of postural control strategies as well as postural stability in balance tests, which has hitherto not been possible in this field of research. The positive effects of training demonstrated in this study may indicate increased proprioceptive input when balance conditions are challenged and disrupted (Golomer and Dupui, 2000) which merits further investigation.

10.5 Applied implications and recommendations for future research

The findings from this thesis present a number of implications. Field balance tests have been revealed to have weak associations and low predictive strength for performance. These results call into question the assumption that current balance measures are appropriate to assess dancers' balance. Furthermore, the results from the functional time to stabilisation tests challenge the documented assumption that a functional time to stabilisation measure, originally developed for sports people, is suitable for dancers, and therefore, further exploration and development of dance-specific functional measures is recommended. Dancers' employment of balance strategies in training and performance can compensate for balance errors or fatiguing effects and this needs to be considered so that tasks are challenging enough for a dance population.

Study 6 demonstrated that the training effects on some balance tasks may suggest differences in task difficulty. This highlights the need for further consideration of task design to minimise a ceiling effect. Both training protocols included novel approaches, specifically the in-class randomised improvisation training, and the test protocols offered a closer replication of the challenges faced by dancers in class and performance. The balance tasks were embedded into a timed continuous sequence, and this reduced the time for the dancers to rely on their entrenched balance strategies although the effects of this on balance performance remains inconclusive. Examining task difficulty requires a flexible approach and could be explored in a variety of ways in future research. One of the key areas for consideration is how task difficulty might be increased. Dancers have fast anticipatory responses and even if the task is made more technically complex, a dancer can often quickly adapt balance strategies to ensure they achieve the balance. This can become a learned effect, if the tasks are repeated, which may diminish the interpretation of research results. Future research in this area might investigate tests with elements that disrupt the dancer's equilibrium immediately before the balance task. This might include supervised eyes closed training, or wobble board training, or improvised sequences with spontaneous actions that could be applied to further research on balance training. For example, the ICT group received balance training through a randomised series of balances in an improvisation task and demonstrated the best improvement in a challenging balance. There are acknowledged differences in performing tasks in labatories, studios, and performance sites for dancers. Aiming to replicate the performance environment as far as possible, the novel test dance sequence (Study 6) was assessed in dance studios used for performance assessments by the undergraduate participants, and this could be considered in further testing of dance-specific balance tools and protocols.

The novel Accumulation Balance Score has demonstrated reliability, and its potential adaptability for use either in the labatory or studio or performance should be considered for further research. The design of the ABS gives scope for examining the variability in both postural stability and postural control responses which may lead to increased understanding of the complex variabilities in complex tasks. The measure requires further replication to limit study bias and could be applied alongside other measures to gather further information on balance performance.

11 Concluding remarks

The present programme of research examined balance performance in dance, specifically, current and novel approaches to testing and training. Six studies were conducted to test the null hypotheses that associations between balance tests would not be evident, balance ability would not predict performance, the effects of bilaterality and, secondly, fatigue on postural stability would not be demonstrated, and balance training would not elicit differences on postural stability. Results failed to show unequivocal support for some of these hypotheses. Weak associations were shown between some tests, and between some balance ability and performance in Studies 1 and 2 respectively. However, the associations were weak, indicating that current field balance tests may not be effective assessment tools for dancers. No effects of bilateral differences on postural stability were shown, either with, or without, a fatigue intervention in Studies 3 and 4 respectively. This implies that the TTS protocol may not be challenging enough for a dance population. In response to the limitations in assessment and tools found in the earlier studies, a novel, and reliable balance score was developed in Study 5 which assesses data on the complex responses to balance tasks. This unique dance-specific tool can be applied to any dance genre. Balance training effects on postural stability were demonstrated in Study 6. In addition, this study offered a novel approach to training and testing, which presents new dance-specific protocols for future studies.

This thesis contributes to the existing literature by examining methods of assessing balance in a dance population using a range of field tests and labatory tests, and developing novel, reliable, dance-specific assessment tools. The research provides new insights into the mixed findings of the effectiveness of these tools and the complexity of assessing a population with expert balance strategies.

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13 Appendices

13.1 Pre-activity Questionnaire

WOLVERHAMPTON

HUMAN PERFORMANCE EVALUATION

Pre-test Questionnaire

Name...

Date of Birth.. Age..................

As you are to be a participant in this laboratory, would you please answer the following questions truthfully and completely. The purpose of this questionnaire is to ensure that you are in a fit and healthy state to complete the exercise test(s). Your co-operation in this is greatly appreciated. *Please delete where appropriate

ANY INFORMATION CONTAINED HEREIN WILL BE TREATED AS CONFIDENTIAL.

1. How would you describe your present level of activity?
   Sedentary moderately active active highly active*

2. How would you describe your present level of fitness?
   Very unfit moderately fit trained highly trained*

3. How would you consider your present body weight?
   Underweight ideal weight slightly over weight very overweight*

4. Smoking habits:
   Currently a smoker yes/no* A previous smoker yes/no* of......per day
   If previous smoker, how long since stopping?...........years
   An occasional smoker yes/no* of ....per day
   A regular smoker yes/no* of ....per day

5. Consumption of alcohol:
   Do you drink alcoholic drinks? yes/no* If *yes* then do you: have the occasional drink? yes/no*
   Have a drink every day? yes/no* Have more than one drink a day? yes/no*

6. Have you had to consult your doctor within the last 6 months? yes/no*
   If *yes*, please give details to the test supervisor

7 Are you presently taking any form of medication? yes/no*
   If *yes*, please give details to the test supervisor

8. Do you suffer, or have you ever suffered, from:
   Asthma? yes/no* Diabetes? yes/no* Bronchitis? yes/no* Epilepsy? yes/no*
   High blood pressure? yes/no*

9. Do you suffer, or have you ever suffered from, any form of heart complaint? yes/no*

10. Is there history of heart disease in your family? yes/no*

11. Do you currently have any form of muscle or joint injury? yes/no*

12. Have you had any cause to suspend your normal training in the last two weeks? yes/no*

13. Is there anything to your knowledge that may prevent you from successfully completing the tests that have been outlined to you? yes/no*

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

Signature of participant .... Date.....................................

I hereby declare that I have read this form in it's entirety and I understand that the questions asked have been answered to my satisfaction.

Signature of tester ....

13.2 Participant Information and Consent form: Study 1 and 2

<u>Participation Information and Informed Consent</u>

Primary Researcher: Frances Clarke

Supervising Researchers: Prof Matt Wyon, Prof Yiannis Koutedakis, Dr Margaret Wilson

Project Title: Associations between static and dynamic field balance tests in assessing postural stability of undergraduate dancers

Data will also be used for **Associations between balance ability and dance performance using field balance tests** (Study 2)

You are being invited to take part in a research study. Before you decide whether to take part, it is important for you to understand why the research is being conducted and what it will involve. Please take the time to tread the following information carefully and decide if you want to take part in this study. Please feel free to ask questions if there is anything that is not clear of if you would like more information.

What is the purpose of the study? This study aims to examine associations between balance tests used to test dancers

What does the study involve? You will be asked to perform five different balance tests. There will be a short rest time between each test. You will be provided with full instructions on how to complete the tasks. We ask that you try to do your best on every task. The entire study will last less than 30 minutes.

Are there any risks involved? The risks can be minimised by warming up beforehand and cooling down afterwards.

What happens to the information I provide? The information you provide will be confidential. The data collected from the research will be anonymised by assigning each participant with a number rather than by name, in accordance with the Data Protection Act of 1998. Data will be used for research purposes only and confidentially will be maintained in any publications arising from the study. No one apart from the researcher Frances Clarke and project supervisors Prof Matt Wyon, Prof Yiannis Koutedakis, and Dr Margaret Wilson will have access to the information you provide. Your consent form will be kept separate from the data collected during the course of the study. A summary of the results will be available from the experimenter on request once the study is complete.

Do I have to take part? Participation in this study is totally voluntary, you are under no obligation to take part in this study. The data that you provide will be very useful for our study. If you decide to take part you will be given this information sheet to keep and will be asked to sign a consent form. You have the right to withdraw from the study at any time and without giving a reason.

Now is your opportunity to ask any questions about the project.

Thank you for taking the time to read the participant information sheet and considering whether to take part in the project.

If you require any further information, please contact either the investigator (Frances Clarke, [e-mail address redacted] or one of the other project supervisors (Prof Matt Wyon, [e-mail address redacted])

Please place a cross in the box to confirm that:

1. I have read and understand the information sheet for the above study and have had opportunity to ask questions. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason. ☐
3. I agree to take part in the above study and agree to the terms ☐

   Engaging in physical activities:
4. I have completed a pre-exercise health screening form alongside this consent form ☐

………………………………..... ………………… ….........

Name of participant [printed] **Signature** **Date**

……………………………… ………………….. …………

Investigator [printed] **Signature** **Date**

13.3 Participant Information and Consent form: Study 3

<u>Participation Information and Informed Consent</u>

Primary Researcher: Frances Clarke

Supervising Researchers: Prof Matt Wyon, Prof Yiannis Koutedakis, Dr Margaret Wilson

Project Title: Bilateral differences on dancers' dynamic postural stability during jump landing

You are being invited to take part in a research study. Before you decide whether to take part, it is important for you to understand why the research is being conducted and what it will involve. Please take the time to tread the following information carefully and decide if you want to take part in this study. Please feel free to ask questions if there is anything that is not clear of if you would like more information.

What is the purpose of the study? This study aims to examine the differences between legs (bilateral) in jump landings.

What does the study involve? You will be asked to perform a short series of jumps over a low bar (50% of your maximum jump height) onto a force plate. You will be provided with full instructions on how to complete the tasks. We ask that you try to do your best on every task. The entire study will last less than 10 minutes.

Are there any risks involved? The risks can be minimised by warming up beforehand and cooling down afterwards.

What happens to the information I provide? The information you provide will be confidential. The data collected from the research will be anonymised by assigning each participant with a number rather than by name, in accordance with the Data Protection Act of 1998. Data will be used for research purposes only and confidentially will be maintained in any publications arising from the study. No one apart from the researcher Frances Clarke and project supervisors Prof Matt Wyon, Prof Yiannis Koutedakis, and Dr Margaret Wilson will have access to the information you provide. Your consent form will be kept separate from the data collected during the course of the study. A summary of the results will be available from the experimenter on request once the study is complete.

Do I have to take part? Participation in this study is totally voluntary, you are under no obligation to take part in this study. The data that you provide will be very useful for our study. If you decide to take part you will be given this information sheet to keep and will be asked to sign a consent form. You have the right to withdraw from the study at any time and without giving a reason.

Now is your opportunity to ask any questions about the project.

Thank you for taking the time to read the participant information sheet and considering whether to take part in the project.

If you require any further information, please contact either the investigator (Frances Clarke, [e-mail address redacted]) or one of the other project supervisors (Prof Matt Wyon, [e-mail address redacted])

Please place a cross in the box to confirm that:

1. I have read and understand the information sheet for the above study and have had opportunity to ask questions. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason. ☐
3. I agree to take part in the above study and agree to the terms ☐

Engaging in physical activities:

4. I have completed a pre-exercise health screening form alongside this consent form ☐

……………………………….....	…………………	…..........
Name of participant [printed]	**Signature**	**Date**
………………………………	…………………..	…………
Investigator [printed]	**Signature**	**Date**

13.4 Participant Information and Consent form: Study 4

UNIVERSITY OF WOLVERHAMPTON

Participation Information and Informed Consent

Primary Researcher: Frances Clarke

Supervising Researchers: Prof Matt Wyon, Prof Yiannis Koutedakis, Dr Margaret Wilson

Project Title: Effects of fatigue on bilateral differences on dancers' dynamic postural stability during landing using a time to stabilisation protocol

You are being invited to take part in a research study. Before you decide whether to take part, it is important for you to understand why the research is being conducted and what it will involve. Please take the time to tread the following information carefully and decide if you want to take part in this study. Please feel free to ask questions if there is anything that is not clear of if you would like more information.

What is the purpose of the study? This study aims to examine the differences between legs (bilateral) in jump landings after a fatigue intervention.

What does the study involve? You will be asked to perform a short series of jumps over a low bar (50% of your maximum jump height) onto a force plate. Afterwards you will perform the Dance Aerobic Fitness Test (20 minutes' duration), and then repeat the jump series protocol. You will be provided with full instructions on how to complete the tasks. We ask that you try to do your best on every task. The entire study will take approximately 30 minutes.

Are there any risks involved? The risks can be minimised by warming up beforehand and cooling down afterwards.

What happens to the information I provide? The information you provide will be confidential. The data collected from the research will be anonymised by assigning each participant with a number rather than by name, in accordance with the Data Protection Act of 1998. Data will be used for research purposes only and confidentially will be maintained in any publications arising from the study. No one apart from the researcher Frances Clarke and project supervisors Prof Matt Wyon, Prof Yiannis Koutedakis, and Dr Margaret Wilson will have access to the information you provide. Your consent form will be kept separate from the data collected during the course of the study. A summary of the results will be available from the experimenter on request once the study is complete.

Do I have to take part? Participation in this study is totally voluntary, you are under no obligation to take part in this study. The data that you provide will be very useful for our study. If you decide to take part you will be given this information sheet to keep and will be asked to sign a consent form. You have the right to withdraw from the study at any time and without giving a reason.

Now is your opportunity to ask any questions about the project.

Thank you for taking the time to read the participant information sheet and considering whether to take part in the project.

If you require any further information, please contact either the investigator (Frances Clarke, [e-mail address redacted]) or one of the other project supervisors (Prof Matt Wyon, [e-mail address redacted])

Please place a cross in the box to confirm that:

1. I have read and understand the information sheet for the above study and have had opportunity to ask questions. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason. ☐
3. I agree to take part in the above study and agree to the terms ☐

Engaging in physical activities:

4. I have completed a pre-exercise health screening form alongside this consent form ☐

…………………………….....	…………………	…..........
Name of participant [printed]	**Signature**	**Date**
………………………………	…………………..	…………
Investigator [printed]	**Signature**	**Date**

13.5 Participant Information and Consent form: Study 6

<u>Participation Information and Informed Consent</u>

Primary Researcher: Frances Clarke

Supervising Researchers: Prof Matt Wyon, Prof Yiannis Koutedakis, Dr Margaret Wilson

Project Title: Balance training differences on dancers' dynamic postural stability: A randomised controlled trial

You are being invited to take part in a research study. Before you decide whether to take part, it is important for you to understand why the research is being conducted and what it will involve. Please take the time to tread the following information carefully and decide if you want to take part in this study. Please feel free to ask questions if there is anything that is not clear of if you would like more information.

What is the purpose of the study? This study aims to examine the differences between different training protocols on dancers' postural stability.

What does the study involve? You will be randomly assigned to a group (supplementary training, in class training or control). If in a training group, you will participate in a four week training programme twice a week. You will perform a short dance sequence before and after the training programme intervention period. You will be provided with full instructions on how to complete the tasks. We ask that you try to do your best on every task. The entire study will take just over four weeks including the pre- and post-testing. No training session will take longer than 30 minutes.

Are there any risks involved? The risks can be minimised by warming up beforehand and cooling down afterwards.

What happens to the information I provide? The information you provide will be confidential. The data collected from the research will be anonymised by assigning each participant with a number rather than by name, in accordance with the Data Protection Act of 1998. Data will be used for research purposes only and confidentially will be maintained in any publications arising from the study. No one apart from the researcher Frances Clarke and project supervisors Prof Matt Wyon, Prof Yiannis Koutedakis, and Dr Margaret Wilson will have access to the information you provide. Your consent form will be kept separate from the data collected during the course of the study. A summary of the results will be available from the experimenter on request once the study is complete.

Do I have to take part? Participation in this study is totally voluntary, you are under no obligation to take part in this study. The data that you provide will be very useful for our study. If you decide to take part you will be given this information sheet to keep and will be asked to sign a consent form. You have the right to withdraw from the study at any time and without giving a reason.

Now is your opportunity to ask any questions about the project.

Thank you for taking the time to read the participant information sheet and considering whether to take part in the project.

If you require any further information, please contact either the investigator (Frances Clarke, [e-mail address redacted]) or one of the other project supervisors (Prof Matt Wyon, [e-mail address redacted])

Please place a cross in the box to confirm that:

1. I have read and understand the information sheet for the above study and have had opportunity to ask questions. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason. ☐
3. I agree to take part in the above study and agree to the terms ☐

Engaging in physical activities:

4. I have completed a pre-exercise health screening form alongside this consent form ☐

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Name of participant [printed]	**Signature**	**Date**
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Investigator [printed]	**Signature**	**Date**

13.6 Instruction sheet for In Class Training (ICT) for Study 6: session 1

Balance Intervention Study

Randomised In Class Training (ICT) protocol (lecturer's instructions):

Two-minute improvisation (theme to be of your choice but relating to your class if preferred).

You need a phone with stopwatch/clock.

In class training group only, (others to continue with end of warm up activities). There will be 4 types of balances: R leg flat, L leg flat, R leg demi, L leg demi (order varies).

Before the training task: check the relevant students are ready in the space. Explain the theme of improvisation as it relates to your chosen idea. Then state the following: "This improvisation needs to be continuous and done as fully as possible so that there is no sense of 'marking' at any time. At various points I will say 'Stop! Balance on…either the right or left leg, and either flat or demi pointe (eg. Stop! Balance right leg flat)" [please give other examples if they look confused!]. "Hold the balance for as long as possible and at a given point…" [5 secs] "…I will say 'Start' and you continue improvising. Make every effort to not put down your non-supporting leg, arms/torso may be used to counterbalance but only if necessary". [Practise a few secs of improvisation and a command of your choice.]
Start: **week 1, session 1 (1/8)**
Stop @ 10 secs Command: "Stop. Balance left leg flat. Hold" Continue stopwatch and at 15 secs (so another 5 secs on) command: "Go"
Stop @ 25 secs Command: "Stop. Balance right leg demi. Hold" Continue stopwatch and at 30 secs, command: "Go"
Stop @ 36 secs Command: "Stop. Balance left leg demi. Hold" Continue stopwatch and at 41 secs, command: "Go"
Stop @ 50 secs Command: "Stop. Balance right leg flat. Hold" Continue stopwatch and at 55 secs, command: "Go"
Stop @ 1:03 secs Command: "Stop. Balance right leg demi. Hold" Continue stopwatch and at 1:08 secs, command: "Go"
Stop @ 1:20 secs Command: "Stop. Balance left leg flat. Hold" Continue stopwatch and at 1:25 secs, command: "Go"
Stop @ 1:40 secs Command: "Stop. Balance left leg demi. Hold" Continue stopwatch and at 1:45 secs, command: "Go"
Stop @ 1:48 secs Command: "Stop. Balance right leg flat. Hold" Continue stopwatch and at 1:53 secs, command: "Go"
As they start again, command: "And slowly bring to a close…" and finish @ 2:00

13.7 Instruction sheet for In Class Training (ICT) for Study 6: session 2

Balance Intervention Study

Randomised In Class Training (ICT) protocol (lecturer's instructions):

Two-minute improvisation (theme to be of your choice but relating to your class if preferred).

You need a phone with stopwatch/clock.

In class training group only, (others to continue with end of warm up activities). There will be 4 types of balances: R leg flat, L leg flat, R leg demi, L leg demi (randomised order of balance tasks and time).

Before the training task: check the relevant students are ready in the space. Explain the theme of improvisation as it relates to your chosen idea. (Reminder to students if required: "This improvisation needs to be continuous and done as fully as possible so that there is no sense of 'marking' at any time. At various points I will give a balance command (eg. Right leg flat). Hold the balance for as long as possible and at a given point I will say 'Go' and you continue improvising. Make every effort to **not** put down your gesture leg, and arms/torso may be used to counterbalance but only if necessary".)
Start: **week 1, session 2 (2/8)**
Stop @ **7** second(s) Command: "**Left flat**. Hold" Continue stopwatch and at **12**s (so another 5 secs on) command: "Go"
Stop @ **53**s Command: "**Right demi**. Hold" Continue stopwatch and at **58**s, command: "Go"
Stop @ **1:02**s Command: "**Right flat**. Hold" Continue stopwatch and at **1:07**s, command: "Go"
Stop @ **1:12**s Command: "**Left demi**. Hold" Continue stopwatch and at **1:17**s, command: "Go"
Stop @ **1:21**s Command: "**Right demi**. Hold" Continue stopwatch and at **1:26**s, command: "Go"
Stop @ **1:30**s Command: "**Right flat**. Hold" Continue stopwatch and at **1:35**s, command: "Go"
Stop @ **1:42**s Command: "**Left flat**. Hold" Continue stopwatch and at **1:47**s, command: "Go"
Stop @ **1:55**s Command: "**Left demi**. Hold" Continue stopwatch and at end at **2:00**mins.

13.8 Instruction sheet for In Class Training (ICT) for Study 6: session 3

Balance Intervention Study

Randomised In Class Training (ICT) protocol (lecturer's instructions):

Two-minute improvisation (theme to be of your choice but relating to your class if preferred).

You need a phone with stopwatch/clock.

In class training group only, (others to continue with end of warm up activities). There will be 4 types of balances: R leg flat, L leg flat, R leg demi, L leg demi (randomised order of balance tasks and time).

Before the training task: check the relevant students are ready in the space. Explain the theme of improvisation as it relates to your chosen idea. (Reminder to students if required: "This improvisation needs to be continuous and done as fully as possible so that there is no sense of 'marking' at any time. At various points I will give a balance command (eg. Right leg flat). Hold the balance for as long as possible and at a given point I will say 'Go' and you continue improvising. Make every effort to **not** put down your gesture leg, and arms/torso may be used to counterbalance but only if necessary".)
Start: **week 2, session 3 (3/8)**
Stop @ **5** second(s) Command: "**Left demi**. Hold" Continue stopwatch and at **10**s (so another 5 secs on) command: "Go"
Stop @ **15**s Command: "**Right demi**. Hold" Continue stopwatch and at **20**s, command: "Go"
Stop @ **26**s Command: "**Left flat**. Hold" Continue stopwatch and at **31**s, command: "Go"
Stop @ **36**s Command: "**Right flat**. Hold" Continue stopwatch and at **41**s, command: "Go"
Stop @ **45**s Command: "**Right demi**. Hold" Continue stopwatch and at **51**s, command: "Go"
Stop @ **1:04**s (1 min 4s) Command: "**Left demi**. Hold" Continue stopwatch and at **1:09**s, command: "Go"
Stop @ **1:30**s Command: "**Right flat**. Hold" Continue stopwatch and at **1:35**s, command: "Go"
Stop @ **1:42**s Command: "**Left flat**. Hold" Continue stopwatch and at end at **1:47**mins.

13.9 Instruction sheet for In Class Training (ICT) for Study 6: session 4

Balance Intervention Study

Randomised In Class Training (ICT) protocol (lecturer's instructions):

Two-minute improvisation (theme to be of your choice but relating to your class if preferred).

You need a phone with stopwatch/clock.

In class training group only, (others to continue with end of warm up activities). There will be 4 types of balances: R leg flat, L leg flat, R leg demi, L leg demi (randomised order of balance tasks and time).

Before the training task: check the relevant students are ready in the space. Explain the theme of improvisation as it relates to your chosen idea. (Reminder to students if required: "This improvisation needs to be continuous and done as fully as possible so that there is no sense of 'marking' at any time. At various points I will give a balance command (eg. Right flat). Hold the balance for as long as possible and at a given point I will say 'Go' and you continue improvising. Make every effort to **not** put down your gesture leg, and arms/torso may be used to counterbalance but only if necessary".)
Start: **week 2, session 4 (4/8)**
Stop @ **10** second(s) Command: "**Right demi**. Hold" Continue stopwatch and at **15**s (so another 5 secs on) command: "Go"
Stop @ **23**s Command: "**Left flat**. Hold" Continue stopwatch and at **28**s, command: "Go"
Stop @ **47**s Command: "**Left demi**. Hold" Continue stopwatch and at **52**s, command: "Go"
Stop @ **1:00**s (1 min) Command: "**Right flat**. Hold" Continue stopwatch and at **1:05**s, command: "Go"
Stop @ **1:17**s Command: "**Left flat**. Hold" Continue stopwatch and at **1:22**s, command: "Go"
Stop @ **1:30**s (1 min 4s) Command: "**Right demi**. Hold" Continue stopwatch and at **1:35**s, command: "Go"
Stop @ **1:43**s Command: "**Right flat**. Hold" Continue stopwatch and at **1:48**s, command: "Go"
Stop @ **1:52**s Command: "**Left demi**. Hold" Continue stopwatch and at end at **1:57**mins.

13.10 Instruction sheet for In Class Training (ICT) for Study 6: session 5

Balance Intervention Study

Randomised In Class Training (ICT) protocol (lecturer's instructions):

Two-minute improvisation (theme to be of your choice but relating to your class if preferred).

You need a phone with stopwatch/clock.

In class training group only, (others to continue with end of warm up activities). There will be 4 types of balances: R leg flat, L leg flat, R leg demi, L leg demi (randomised order of balance tasks and time).

(Reminder to students if required: "This improvisation needs to be continuous and done as fully as possible so that there is no sense of 'marking' at any time. At various points I will give a balance command (eg. Right flat). Hold the balance and at a given point I will say 'Go' and you continue improvising. Make every effort to **not** put down your gesture leg. **Weeks 3 & 4:** **1) Balances are 7 secs (see below)** 2) **Please instruct the participants to keep moving their gesture limbs during the <u>flat foot balances</u> (dynamic balances)**
Start: w**eek 3, session 5 (5/8)**
Stop @ **19** second(s) Command: "**Left demi**. Hold" Continue stopwatch and at **26**s (**so another 7 secs on**) command: "Go"
Stop @ **32**s Command: "**Right demi**." Continue stopwatch and at **39**s, command: "Go"
Stop @ **55**s Command: "**Left flat, keep moving arms & right leg**." Continue stopwatch and at **1:02**mins, command: "Go"
Stop @ **1:08**mins Command: "**Right flat, keep moving arms & left leg**." Continue stopwatch and at **1:15**mins, command: "Go"
Stop @ **1:18**mins Command: "**Right flat, keep moving arms & left leg**." Continue stopwatch and at **1:25**mins, command: "Go"
Stop @ **1:32**mins Command: "**Right demi**." Continue stopwatch and at **1:39**mins, command: "Go"
Stop @ **1:44**mins Command: "**Left demi**." Continue stopwatch and at **1:51**mins, command: "Go"
Stop @ **1:53**mins Command: "**Left flat**, **keep moving arms & right leg**." Continue stopwatch and at end at **2:00**mins.

13.11 Instruction sheet for In Class Training (ICT) for Study 6: session 6

Balance Intervention Study

Randomised In Class Training (ICT) protocol (lecturer's instructions):

Two-minute improvisation (theme to be of your choice but relating to your class if preferred).

You need a phone with stopwatch/clock.

In class training group only, (others to continue with end of warm up activities). There will be 4 types of balances: R leg flat, L leg flat, R leg demi, L leg demi (randomised order of balance tasks and time).

(Reminder to students if required: "This improvisation needs to be continuous and done as fully as possible so that there is no sense of 'marking' at any time. At various points I will give a balance command (eg. Right leg flat). Hold the balance and at a given point I will say 'Go' and you continue improvising. Make every effort to **not** put down your gesture leg. **Weeks 3 & 4:** **1) Balances are 7 secs (see below)** 2) **Please instruct the participants to keep moving their gesture limbs during the <u>flat foot balances</u> (dynamic balances)**
Start: w**eek 3, session 6 (6/8)**
Stop @ **15** second(s) Command: "**Right flat, keep moving arms & leg**." Continue stopwatch and at **22**s (**so another 7 secs on**) command: "Go"
Stop @ **38**s Command: "**Right demi**." Continue stopwatch and at **45**s, command: "Go"
Stop @ **54**s Command: "**Left flat, keep moving arms & leg**." Continue stopwatch and at **1:01**mins, command: "Go"
Stop @ **1:11**mins Command: "**Left demi**." Continue stopwatch and at **1:18**mins, command: "Go"
Stop @ **1:23**mins Command: "**Right flat, keep moving arms & leg**." Continue stopwatch and at **1:30**mins, command: "Go"
Stop @ **1:34**mins Command: "**Left flat, keep moving arms & leg**." Continue stopwatch and at **1:41**mins, command: "Go"
Stop @ **1:43**mins Command: "**Right demi**." Continue stopwatch and at **1:50**mins, command: "Go"
Stop @ **1:53**mins Command: "**Left demi**." Continue stopwatch and at end at **2:00**mins.

13.12 Instruction sheet for In Class Training (ICT) for Study 6: session 7

Balance Intervention Study

Randomised In Class Training (ICT) protocol:

Two-minute improvisation (theme to be of your choice but relating to your class if preferred).

You need a phone with stopwatch/clock.

In class training group only, (others to continue with end of warm up activities). There will be 4 types of balances: R leg flat, L leg flat, R leg demi, L leg demi (randomised order of balance tasks and time).

(Reminder to students if required: "This improvisation needs to be continuous and done as fully as possible so that there is no sense of 'marking' at any time. At various points I will give a balance command (eg. Right flat). Hold the balance and at a given point I will say 'Go' and you continue improvising. Make every effort to **not** put down your gesture leg. **Weeks 3 & 4:** **1) Balances are 7 secs (see below)** 2) **Please instruct the participants to keep moving their gesture limbs during the <u>flat foot balances</u> (dynamic balances)**
Start: w**eek 4, session 7 (7/8)**
Stop @ **11** second(s) Command: "**Left flat, keep moving arms & leg**." Continue stopwatch and at **18**s (**so another 7 secs on**) command: "Go"
Stop @ **21**s Command: "**Right flat**, **keep moving arms & leg**." Continue stopwatch and at **28**s, command: "Go"
Stop @ **32**s Command: "**Right demi**." Continue stopwatch and at **39**s, command: "Go"
Stop @ **42**s Command: "**Left demi**." Continue stopwatch and at **49**s, command: "Go"
Stop @ **57**s Command: "**Right demi**." Continue stopwatch and at **1:04**mins, command: "Go"
Stop @ **1:14**mins Command: "**Left demi**." Continue stopwatch and at **1:21**mins, command: "Go"
Stop @ **1:23**mins Command: "**Left flat, keep moving arms & leg**." Continue stopwatch and at **1:30**mins, command: "Go"
Stop @ **1:40**mins Command: "**Right flat, keep moving arms & leg**." Continue stopwatch and at end at **1:47**mins.

13.13 Instruction sheet for In Class Training (ICT) for Study 6: session 8

Balance Intervention Study

Randomised In Class Training (ICT) protocol (lecturer's instructions):

Two-minute improvisation (theme to be of your choice but relating to your class if preferred).

You need a phone with stopwatch/clock.

In class training group only, (others to continue with end of warm up activities). There will be 4 types of balances: R leg flat, L leg flat, R leg demi, L leg demi (randomised order of balance tasks and time).

(Reminder to students if required: "This improvisation needs to be continuous and done as fully as possible so that there is no sense of 'marking' at any time. At various points I will give a balance command (eg. Right flat). Hold the balance and at a given point I will say 'Go' and you continue improvising. Make every effort to **not** put down your gesture leg. **Weeks 3 & 4:** **1) Balances are 7 secs (see below)** 2) **Please instruct the participants to keep moving their gesture limbs during the <u>flat foot balances</u> (dynamic balances)**
Start: w**eek 4, session 8 (8/8)**
Stop @ **31** second(s) Command: "**Left demi**." Continue stopwatch and at **38**s (**so another 7 secs on**) command: "Go"
Stop @ **45**s Command: "**Right demi**." Continue stopwatch and at **52**s, command: "Go"
Stop @ **56**s Command: "**Left flat, keep moving arms & leg**." Continue stopwatch and at **1:03**mins, command: "Go"
Stop @ **1:06**mins Command: "**Right flat, keep moving arms & leg**." Continue stopwatch and at **1:13**mins, command: "Go"
Stop @ **1:20**mins Command: "**Right demi**." Continue stopwatch and at **1:27**mins, command: "Go"
Stop @ **1:30**mins Command: "**Left demi**." Continue stopwatch and at **1:37**mins, command: "Go"
Stop @ **1:43**mins Command: "**Right flat, keep moving arms & leg**." Continue stopwatch and at **1:50**mins, command: "Go"
Stop @ **1:53**mins Command: "**Left flat, keep moving arms & leg**." Continue stopwatch and at end at **2:00**mins.

13.14 Accumulation Balance Score scoring sheet

Assessor initials:

Participant ID:							
Jump 1	Arms	1	2	3	4	5	Time (secs):
	Legs	1	2	3	4	5	Loss of control
	Spine	1	2	3	4	5	(tick if applicable):
2	Arms	1	2	3	4	5	Time (secs):
	Legs	1	2	3	4	5	Loss of control
	Spine	1	2	3	4	5	(tick if applicable):
3	Arms	1	2	3	4	5	Time (secs):
	Legs	1	2	3	4	5	Loss of control
	Spine	1	2	3	4	5	(tick if applicable):
4	Arms	1	2	3	4	5	Time (secs):
	Legs	1	2	3	4	5	Loss of control
	Spine	1	2	3	4	5	(tick if applicable):
5	Arms	1	2	3	4	5	Time (secs):
	Legs	1	2	3	4	5	Loss of control
	Spine	1	2	3	4	5	(tick if applicable):
6	Arms	1	2	3	4	5	Time (secs):
	Legs	1	2	3	4	5	Loss of control
	Spine	1	2	3	4	5	(tick if applicable):

13.15 Publications

Blind Peer Review Journals

Clarke, F., Koutedakis, Y., Wilson, M., and Wyon, M. (2018) Balance in dance performance: A systematic review. *Medical Problems of Performing Artists*. **33**(4), pp.276-286

Clarke, F., Koutedakis, Y., Wilson, M., and Wyon, M. (2019) Associations between balance ability and dance performance using field balance tests. *Medical Problems of Performing Artists*. **34**(3), pp. 154-160

Clarke, F., Koutedakis, Y., Wilson, M., and Wyon, M. (2020) Bilateral differences on dancers' dynamic postural stability during jump landing. *Journal of Dance Medicine & Science.* **24**(4), pp.183-189. doi.org/10.12678/1089-313X.24.4.183

Clarke, F., Koutedakis, Y., Wilson, M., and Wyon, M. (in press) Associations between static and dynamic field balance tests in assessing postural stability of undergraduate female dancers. *Journal of Dance Medicine & Science*